10th BIWAES

Biennial International Workshop Advances in Energy Studies

Energy futures, environment and well-being

Scientific Editors: Sergio Ulgiati and Laura Vanoli

Associate Editors: Mark T. Brown, Marco Casazza and Hans Schnitzer

University of Naples 'Parthenope'

Villa Doria D'Angri

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September 25 – 28, 2017

UNIVERSITA' DEGLI STUDI DI NAPOLI PARTHENOPE

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BIWAES 2017

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Preface

The key word of this 10^{th} edition of the Biennial International Workshop Advances in Energy Studies (BIWAES) is "wellbeing". While we certainly need energy efficiency and innovative energy technologies and we also need environmentally friendly production and consumption patterns, what we really need is a better way of living, based on better relations among individuals at local, national and international levels as well as better relations between humans and the other species.

Technological improvement - unless guided by a clear perspective - may not necessarily lead to the desired improvement of quality of life and wellbeing. On the contrary, it might even lead to faster resource depletion, faster environmental degradation, increased social disparity and global instability. During the past BIWAES editions we have explored in depth aspects as energy saving, energy efficiency, rebound effect, growth and de-growth, sustainability, technological innovation, renewability of energy and material resources. We have agreed that we may need all of these, at appropriate time and spatial scales; and that we need tools to monitor, assess, evaluate; and finally, that we also need radically innovative policies and business models, capable to generate at the same time quality of life, jobs, sustainable communities. This has been the basis of our ongoing research activity, collaboration, exchange of results through publications and meetings in the past years.

The first goal of BIWAES 2017 is therefore to update and exchange our main research results and focus on both the state of the art and the still unsolved problems. This is going to be primarily performed by means of 3 interactive poster sessions and 14 panel sessions dealing with our most updated research activity about urban systems, integrated transportation patterns, food/water/commodity nexus, transition from fossil to low-carbon and renewable resources, sustainable business models, energy efficiency and effective energy strategies, stakeholders and participatory processes, appropriate interplay of humanity and environment, integrated cleaner production and circular economy, pollution control, bioenergy and bio-based materials, empowerment of new actors in the global energy market. In so doing, the state of the art of energy technologies and societal impact will be assessed and discussed as well as collaborative research networks can be implemented towards needed critical mass and worldwide knowledge sharing. The expected result is a further implementation of innovative joint projects on energy future as well as on sustainable production and consumption patterns.

The present BIWAES edition also aims at taking a deep look into energy future. Future must be imagined, designed and implemented. For this to be possible, we need visions and visionaries, much beyond the present state of the art. This is the goal of the planned six thematic, design-oriented working groups (WG) on energy futures and participatory tools and roadmaps, not intended for presentation of personal research results, but instead as creative brainstorming and designing sessions on hot topics characterized by special policy interest and needs:

WG1. Implementing energy efficiency, barriers and solutions. From theory to practice.
WG2. Renewable and nonrenewable energies between growth and de-growth patterns.
WG3. Energy and cleaner production. Innovative designs and technologies.
WG4. Internet of things and the energy sector in urban and industrial systems.
WG5. Socio-economic variables in designing local energy policies.
WG6. Stakeholders and energy planning.

Radically innovative networks, projects, concepts and business models are the expected results of these design-oriented working groups.

Last but not least, energy and development. No need to underline that energy is among the most important development drivers and engines. Too many countries still suffer from energy poverty, in the form of insufficient, inadequate, expensive or unequal energy supply. Although we cannot claim energy to be the solution, the magic bullet to all world problems, we are well aware that there is energy behind water supply, food production, mobility, housing, health, education, communication, democracy. It is not just a matter of energy supply (e.g. cheap fossil fuels; development of renewable energy sources), but a clear need for a mix of solutions, from energy efficiency to appropriate energy use (matching of use to energy quality), from equal energy access by all social groups to appropriate investments for development of opportunities instead of luxury. Energy is still one of the causes of political and economic instability and turmoil worldwide as well as of unequal development of local economies. Wellbeing has very much to do with development/energy nexus.

I maintain that the only purpose of science is to ease the hardship of human existence. If scientists, intimidated by self-seeking people in power, are content to amass knowledge for the sake of knowledge, then science can become crippled, and your new machines will represent nothing but new means of oppression. With time you may discover all that is to be discovered, and your progress will only be a progression away from mankind. The gulf between you and them can one day become so great that your cry of jubilation over some new achievement may be answered by a universal cry of horror. (Life of Galileo, by Bertolt Brecht)

We have asked a few keynote visionaries to help us look into the present and the future of energy and wellbeing, by addressing beyond growth, back to the future, sustainable complexity, integrated planning, circular economy, renewable poly-generation, wastewater energy, energy and food, energy and cities issues and aspects. The present state of the planet urgently calls for deeper understanding, innovative visions, environmentally friendly solutions, development and wellbeing. This is going to be BIWAES 2017.

Sergio Ulgiati and Laura Vanoli,
Editors
Mark T. Brown, Marco Casazza and
Hans Schnitzer, Associate Scientific
Editors

Biennial International Workshop Advances in Energy Studies 2017

BIWAES 2017

WORKSHOP PROGRAMME

Monday 25th September

8.00-9.00	***Registration and welcome coffee***
9.00-9.30	***Welcome addresses*** **Laura Vanoli**, Department of Engineering, 'Parthenope' University of Napoli. **Sergio Ulgiati**, BIWAES workshop series founder, Department of Science and Technology, 'Parthenope' University of Napoli. **Alberto Carotenuto,** Rector, 'Parthenope' University of Napoli
Session Chair: **Riccardo Basosi**, Department of Chemistry, University of Siena (Italy)	
9.30-10.15	***Opening lecture:*** **Beyond growth: Economics as if the planet mattered** **Mark T. Brown**, Director of the "H.T. Odum" Center for Environmental Policy, University of Florida **Sergio Ulgiati**, Department of Science and Technology, 'Parthenope' University of Napoli.
10.15-10.30	***Questions and Comments***
10.30-10.45	***Coffee break***
10.45-11.30	***Keynote Lecture:*** **Back to the Future** **Gilberto Gallopin**, Buenos Aires, Argentina. Independent Scholar and Associate Fellow of the Tellus Institute
11.30-11.45	***Questions and Comments***
11.45-13.00	***Poster Session 1*** *Chaired by:* **Massimiliano Lega**, Parthenope University, Napoli, Italy 1. **Amaya Martínez-Gracia, Alejandro Del Amo, Angel A. Bayod-Rújula, Isabel Guedea.** Performance analysis and experimental validation of a solar-assisted heat pump fed by photovoltaic-thermal collectors. 2. **Marco Raugei and Patricia Winfield.** Prospective LCA of the production and EoL recycling of a novel type of Li-ion batteries for electric vehicles 3. **Luis Acevedo, Javier Uche, Fernando Cirez, Sergio Usón, Amaya Martínez-Gracia, Angel A. Bayod-Rújula.** Experimental analysis of a domestic trigeneration scheme feed by photovoltaic/thermal (PVT) collectors

	4. **<u>Massimiliano Lega</u>, Marco Casazza, Vincenzo Severino, Pier Luigi Accardo**. Energy demand and environmental impacts of an Italian slum: a preliminary analysis. 5. **Arno P. Clasen, <u>Feni Agostinho</u>.** Energetic-environmental performance of the Brazilian offshore pre-salt oil 6. **<u>Antonio Lubrano Lavadera</u>, David Sanchez, Stefano Ubertini, Mariagiovanna Minutillo, Elio Jannelli.** Compressed air energy storage system optimization: comparison between sizing strategies depending on the time horizon of storage. 7. **<u>Simonluca Russo</u>, Vesselin Krassimirov Krastev, Giacomo Falcucci**. Experimental assessment of impact energy in oblique and asymmetric water entry. 8. **<u>Rosa Anna Nastro</u>, Maria Toscanesi, Edvige Gambino, Fabio Flagiello, Giacomo Falcucci, Elio Jannelli, Luciano Ferrara, Marco Trifuoggi.** Microbial Fuel Cells (MFCs) remediation activity of marine sediments sampled at a dismissed industrial site: what opportunities?
11.45-13.00	***Poster Session 2*** *Chaired by:* **Cecilia M. V. B. Almeida**, UNIP-Universidade Paulista, Sao Paulo, Brazil 1. **<u>Amalia Zucaro</u>, Annachiara Forte, Angelo Fierro.** The environmental impacts of wheat straw-based lignocellulosic ethanol for transport sector in a biorefinery prospective. 2. **<u>Dewei Yang</u>.** Evaluating rural developing dynamics using a combined emergy and niche method in a watershed 3. **Enrique Ortega, José Maria Gusman-Ferraz, <u>Mariana Oliveira</u>, Anna Lewandowska-Czarnecka.** A reflection about the Emergy Analysis of Agricultural Systems by focusing on the agroecological transition process 4. **<u>Cecilia M. V. B. Almeida</u>, Mirtes V. Mariano, Biagio F. Giannetti.** Emergy Assessment as a management tool for urban parks 5. **Marco Casazza, Yan Gao, Xinyu Liu, Fanxin Meng, <u>Jinyan Xue</u>, Gengyuan Liu, Sergio Ulgiati**. Water-Energy-Food urban planning: The Urban Circular Economy Calculator (UCEC) 6. **<u>Anna Lewandowska-Czarnecka</u>, Agnieszka Piernik, Andrzej Nienartowicz.** Sustainability indicators in different type of farms. A case study from Poland. 7. **Karabee Das, Greeshma Pradhan, <u>Sanderine Nonhebel</u>**. Quantifying Human energy expenditure in cooking systems in rural areas in developing countries. 8. **<u>Vasile Dogaru</u>, Claudiu Brandas.** A real (non-pseudo) spatial index for neutral CO2 for urban micro-zone in temperate continental climate
11.45-13.00	***Poster Session 3*** *Chaired by:* **Francesco Gonella**, Ca' Foscari University, Venice, Italy 1. **<u>Marco Casazza</u>, Paolo de Vingo, Wim Vandewiele, Sergio Ulgiati.** Environmental resources, economy, regulations: a lack of Community-Based Adaptation for two Medieval monastic communities 2. **<u>Riccardo Basosi</u>, Angelo Facchini, Antonio Scala, Renata Mele, Maria Laura Parisi, Luca Valori.** Investigation of rebound effect in energy consumption of megacities 3. **<u>Verena Helen van Zyl-Bulitta</u>, Jamen Gien Varney-Wong, William Stafford.** A mapping and navigation approach for energy system option spaces on techno-, management- and socio-scales across the Global North-South 4. **<u>Renato Francesco Rallo</u>**. Candles in the dark: a review of environmental and sustainability indicators and their criticisms 5. **<u>Francesco Spano</u>.** Resilience indicators, energy limitations and leverage points: who controls the controllers 6. **<u>Gabriella Duca.</u>** Usability of in-home energy displays and energy saving: a

	design case **7.** **<u>Flavio Picone</u>, Elvira Buonocore, Riccardo D'Agostaro, Stefano Donati, Pier Paolo Franzese, Riccardo Chemello.** Assessing ecosystem services in the Egadi islands marine protected area: an energy perspective 8. **Gloria Rea, Chiara Cagnazzo, <u>Angelo Riccio</u>, Vincenzo Artale**. Planetary boundaries in a changing climate system: how the Antarctic ozone trend responds to stratospheric dynamics?
13.00-14.30	***Lunch***
14.30-17.30	***Parallel research-oriented panels and symposia.*** ***<u>Panel 1. Mobility of passengers and freight</u>*** *Chaired by:* **Reinhard Haas**, Technical University of Wien, Austria and **Shupei Huang**, China University of Geosciences, Beijing, China 1. **<u>Shupei Huang</u>, Haizhong An, Sergio Ulgiati.** Terrestrial transport modalities in China: a survey of monetary, energy and environmental costs. 2. **<u>Silvio Cristiano</u>, Francesco Gonella, Sofia Spagnolo.** On the Emergy accounting for the evaluation of road transport systems: thoughts for an Italian case study **3.** **<u>Amela Ajanovic</u>, Reinhard Haas.** Energy and mobility: Hydrogen as fuel for mobility and storage for renewable energy 4. **<u>Louisa Jane Di Felice</u>, Maddalena Ripa and Mario Giampietro**. Electric vehicles in the EU: between narrative and quantification 5. **<u>Angelo Fierro</u>, Annachiara Forte, Amalia Zucaro, Roberto Micera and Mario Giampietro.** MuSIASEM approach to evaluate the pertinence of the second generation bioethanol production system. The case study of ligno-cellulosic Arundo donax feedstock for the transport sector in Campania region, Italy. ***<u>Panel 2. Energy and urban systems</u>*** *Chaired by*: **Olga Kordas**, Royal Institute of Technology, Stockholm, Sweden, and **Vasile Dogaru**, West University of Timisoara, Romania 1. **<u>Hans Schnitzer</u>**. Design of a Low-Carbon energy system for a new urban area in an industrial neighborhood **2.** **<u>William Braham</u>, Evan Oskierko-Jeznacki, Jae Min Lee, Barry Silverman, Nasrin Khansari.** E[m]ergy Model of the greater Philadelphia Region 3. **<u>Oleksii Pasichnyi</u>, Jörgen Wallin, Hossein Shahrokni, Olga Kordas.** Data-driven building archetypes' generation for urban building energy modelling **4.** **<u>Marco Molinari</u>, Olga Kordas**. ICT in the built environment: drivers, barriers and uncertainties **5.** **<u>Elena Mazzola</u>, Tiziano Dalla Mora, Fabio Peron, Piercarlo Romagnoni.** The use of integrated energetic analyses on a Venetian historic building **6.** **Laura Pérez Sánchez, Gonzalo Gamboa, <u>Raúl Velasco-Fernández</u>, Maddalena Ripa, Renato F. Rallo, Mario Giampietro.** Energy performance at city level − the societal metabolism of Barcelona ***<u>Panel 3. Food, energy, water and commodity nexus</u>*** *Chaired by:* **Gengyuan Liu**, Beijing Normal University, China, and **Enrique Ortega**, Campinas University, Brazil 1. **<u>Sanderine Nonhebel</u> and Winnie Leenes.** Why becoming a vegetarian is not going to save the world. 2. **F<u>anxin Meng</u>, Gengyuan Liu, Zhifeng Yang, Yuanchao Hu, Marco**

	Casazza, Biagio Fernando Giannetti, Sergio Ulgiati. Tracing urban carbon flow in the global economy system: Consumption vs production perspectives 3. **Francesco Spano.** Land requirements for Mediterranean diet: standard agriculture vs new agroecology 4. **Judith Rodriguez Salcedo and Marina Sanchez De Prager.** Valoración del acervo cultural, en términos de eMergia, en sistemas agroecológicos de la región centro Valle del Cauca- Colombia 5. **Luis Acevedo, Javier Uche, Fernando Cirez, Sergio Usón, Amaya Martínez-Gracia and Angel A. Bayod-Rújula.** Exergy analysis of the transient simulation of a renewable-based trigeneration scheme for domestic water and energy supply 6. **Gengyuan Liu, Marco Casazza, Lixiao Zhang, Yan Hao, Sai Liang, Sergio Ulgiati.** Emergy Accounting System Modeling of Urban Water Metabolic Systems. ***Panel 4. The changing energy basis of economies: Declining fossil availability and transition management*** Chaired by: **Silvio Viglia**, Parthenope University, Napoli, Italy and **Robert A. Herendeen**, Gund Institute for Ecological Economics, University of Vermont, VT (USA) 1. **Umberto Perna.** Reserves at risk: planning with deep uncertainty and high complexity 2. **Fereidoon P. Sioshansi**. How innovation and disruptions are reshaping the future of the power sector 3. **Reinhard Haas.** How to integrate large shares of variable renewables into the electricity system. 4. **Robert Herendeen**. 100% renewable: does this trump carrying capacity? 5. **Rony Parra and Anderson Castro.** Evaluation of energy metabolism in the oil extraction in Ecuador from the application of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) 6. **Cristina Madrid López.** Shale Gas for a Low Carbon Economy? The limitations we have to consider. ***Panel 5. Energy and ecological economics. Sustainable finance. New business models for energy.*** *Chaired by:* **Jesus Ramos-Martin**, IKIAM University, Ecuador and **Xi Ji**, Peking University, China 1. **Gabriella Duca and Guglielmo Trupiano**. Bioeconomy and the challenge of community centered design 2. **Antonio Scala, Angelo Facchini and Umberto Perna**. Portfolio analysis and allocation of renewable sources 3. **Alessandro Sapio.** Exporting volatility through market integration: the case of Sardinia. 4. **Juha Panula-Ontto, Jarmo Vehmas, Ying Chen, Jinxing Jiang, Jyrki Luukkanen and Jari Kaivo-Oja.** Impacts of Main Economic Sectors on Energy Efficiency in the period 2015–2030 in China 5. **Heitor F. Marinho Neto and Feni Agostinho**. Sustainability diagnosis of goods and services: do they work in practice? 6. **Chang T. Chang, Michela Costa, Maurizio La Villetta, Adriano Macaluso, Laura Vanoli and Daniele Piazzullo**. Thermodynamic and economic comparison of biomass drying systems coupled with different technologies of power generation

Tuesday 26th September

Session Chair: **Hans Schnitzer**, Professor Emeritus, Technical University of Graz, Austria	
9.00-9.45	***Keynote Lecture:*** **Sustainability and Well Being: Energy, Technology, and Complexity** **Joseph A. Tainter**, Utah University, USA
9.45-10.00	***Questions and Comments***
10.00-10.45	***Keynote Lecture:*** **Smart Energy Systems and the Plans for Renewable Energy. Perspectives for more Integrated National and European Planning** **Henrik Lund,** Department of Development and Planning, Aalborg University, Denmark
10.45-11.00	***Questions and Comments***
11.00-11.15	***Coffee break***
11.15-13.00	**Thematic, Design-oriented Working Groups on Energy Futures** (thematic groups are not intended for presentation of personal research results, but instead as creative brainstorming and designing sessions on hot topics characterized by special policy interest) • Implementing energy efficiency, barriers and solutions. From theory to practice (*Chaired by:* **Antonio Vrenna**, FEDERESCO, Italy and **Silvio Viglia**, Parthenope University, Italy) • Renewable and nonrenewable energies between growth and de-growth patterns (*Chaired by:* **Barney Foran**, Charles Sturt University, Albury, Australia and **Robert A. Herendeen**, Gund Institute for Ecological Economics, University of Vermont, VT USA) • Energy and cleaner production. Innovative designs and technologies (*Chaired by:* **Cecilia M. V. B. Almeida**, UNIP-Universidade Paulista, Sao Paulo, Brazil) and **Francesco Gonella**, Ca' Foscari University, Venice, Italy
13.00-14.30	***Lunch***
14.30-17.30	***Parallel research-oriented panels and symposia.*** ***<u>Panel 6. Energy efficiency</u>*** *Chaired by:* **Jarmo Vehmas**, University of Turku, Finland, and **Elvira Buonocore**, Parthenope University, Napoli, Italy 1. **<u>Oleksii Pasichnyi</u>, Jörgen Wallin, Fabian Levihn, Hossein Shahrokni and Olga Kordas.** Energy Performance Certificates — new opportunities for data-enabled urban energy policy instruments? 2. **<u>Gianluca Trotta</u>, Joachim Spangenberg and Sylvia Lorek**. Energy efficiency in the residential sector: identification of promising policy instruments and private initiatives among selected European countries 3. **<u>Fabiana Corcelli</u>, Gabriella Fiorentino, Jarmo Vehmas and Sergio Ulgiati.** Energy Efficiency and environmental performance indicators of papermaking from chemical pulp. A Finland case study. **4.** **<u>Jarmo Vehmas</u>, Jari Kaivo-Oja, Jyrki Luukkanen.** Decomposition of Total Primary Energy Supply: Energy Efficiency Trends in the EU-28 Member States in 1990-2013 5. **<u>Mauro Reini</u> and Melchiorre Casisi**. Constructal Law and Thermoeconomic

Optimization

6. **Castrichino Tonino, Balsani Federico, Ferrari Claudio, Graniglia Nicola, Tempesti Duccio.** Boosting energy efficiency in Public Administration. Study case: "Palazzo della Farnesina"

Panel 7. Decision making tools for energy management. Stakeholders and participatory strategies.

Chaired by: **Angelo Facchini,** IMT School for Advanced Studies Lucca, and **Amalia Zucaro**, Federico II University, Napoli, Italy

1. **Jari Kaivo-Oja, Jarmo Vehmas and Jyrki Luukkanen**. Energy Intensity, Energy Consumption and Changes in Energy Intensity in the EU-28 Countries in 1995-2014
2. **Anders Nilsson, Olga Kordas, David Lazarevic.** Influencing Household Energy Consumption: Preliminary Results from a Residential Demand Response Program in Sweden
3. **Kateryna Pereverza and Olga Kordas**. Sustainability through stakeholder learning: participatory backcasting for the heating sector
4. **Chiara Vassillo, Daniela Restaino, Remo Santagata, Silvio Viglia, Jarmo Vehmas, Sergio Ulgiati.** Energy efficiency and stakeholders: Barriers, costs and benefits of implementation. The Naples case study in the EUFORIE Project
5. **Sylvia Lorek and Joachim Spangenberg**. Social innovation for energy sufficiency – methods, results and lessons learnt in the EUFORIE project

Panel 8. Matter and energy flows in the biosphere and human economy

Chaired by: **Pier Paolo Franzese**, Parthenope University of Napoli, Italy, and **Gilberto Gallopin**, Tellus Institute, Argentina

1. **Pier Paolo Franzese, Elvira Buonocore, Flavio Picone, Giovanni F. Russo.** Using environmental accounting to operationalize the Planetary Boundaries framework at local scale in marine ecosystems
2. **Marco Casazza, Joseph A. Tainter, Massimiliano Lega, Silvio Viglia, Gengyuan Liu and Sergio Ulgiati.** Energy features of human Socio-Ecological Systems relevant to the future of civilization
3. **Angelo Riccio, Antonino Staiano, Angelo Ciaramella, Francesco Camastra, Elena Chianese, Efisio Solazzo and Stefano Galmarini**. Ozone production and flows in the boundary layer and its impact on crop yields: an optimal ensemble estimation
4. **Ludmila Skaf, Elvira Buonocore, Stefano Dumontet, Roberto Capone, Pier Paolo Franzese.** Environmental costs and impact of food security in a changing world: The case of Lebanon
5. **Fabiana Zollo, Michela Del Vicario, Walter Quattrociocchi and Antonio Scala.** The Climate Change debate on Facebook: a clash of contrasting narratives beyond rationality

Panel 9. Transition to low-carbon and renewable energies

Chaired by: **Maddalena Ripa**, Autonomous University, Barcelona, Spain and **Marco Raugei**, Oxford Brookes University, UK.

1. **Verena van Zyl-Bulitta, Enrique Kremers and Ralf Otte.** Temporal mechanisms for energy system balancing across different socio-technical scales aligned to the current electricity grid state
2. **Marco Raugei, Enrica Leccisi, Vasilis Fthenakis, Gonzalo Ramirez and Rodrigo Escobar Moragas.** Net energy availability and environmental performance of the Chilean electric grids: potential improvements and opportunities
3. **Angel A. Bayod-Rújula, Luis Acevedo, Javier Uche and Amaya Martínez-**

	Gracia. Improved management of battery and RO demand in grid connected PVT systems in dwellings **4.** **Mateusz Szubel, Beata Matras, Szymon Podlasek and Mariusz Filipowicz**. Development of air manifold for straw – fired batch boiler using experimental and numerical methods 5. **Charlie Gullstrom, Olga Kordas and Marco Molinari.** Sharing Spaces in the Sharing Economy: to save energy, increase well-being or boost innovation? How do new initiatives align with energy transition? 6. **Jaime Cevallos and Jesus Ramos-Martin**. Spatial assessment of the potential of renewable energy: the case of Ecuador
19.00-22.00	***Social Dinner and Concert***

Wednesday 27th September

Session Chair: **Olga Kordas**, Royal Institute of Technology, Stockholm, Sweden	
9.00-9.45	***Keynote Lecture:*** **Optimized resource management through circular economy patterns: Challenges in free-market contexts** **Andrea Genovese**, Logistics and Supply Chain Management Research Centre, Management School, The University of Sheffield, UK
9.45-10.00	***Questions and Comments***
10.00-10.45	***Keynote Lecture:*** **Advanced renewable polygeneration systems producing electricity, heat, cool and water: dynamic simulations and thermo-economic optimization.** **Francesco Calise,** University Federico II – Naples, Italy
10.45-11.00	***Questions and Comments***
11.00-11.15	***Coffee break***
11.15-13.00	**Thematic, Design-oriented Working Groups** on participatory tools and roadmaps for energy futures (thematic groups are not intended for presentation of personal research results, but instead as creative brainstorming and designing sessions on hot topics characterized by special policy interest). • Internet of things and the energy sector in urban and industrial systems (chaired by: **Raffaele Montella**, Parthenope University, Napoli and **Marco Molinari**, KTH, Stockholm, Sweden) • Socio-economic variables in designing local energy policies (chaired by: **Joaquim Spangenberg**, SERI, Sustainable Europe Research Institute, Germany and **Maddalena Ripa**, UAB, Barcelona, Spain) • Stakeholders and energy planning (chaired by: **Sylvia Lorek**, SERI, Sustainable Europe Research Institute, Germany and **Kateryna Pereverza**, KTH, Stockholm, Sweden)
13.00-14.30	***Lunch***
14.30-17.30	**Parallel research-oriented panels and symposia.** ***Panel 10. Energy and industrial cleaner production. The challenge of circular economy*** *Chaired by:* **Hans Schnitzer**, Technical University of Graz, Austria, and **Rosa Anna**

Nastro, Parthenope University, Napoli, Italy

1. **Hugo Alejandro Guillen Trujillo, Luis Manuel Reynosa Morales and Alejandra Guillen García.** Sustainability evaluation of different techniques for concrete mixing based on quality control
2. **Jingyan Xue, Gengyuan Liu, Marco Casazza and Sergio Ulgiati.** LCA-based Emergy Analysis of the Aluminum Production Chain in China
3. **Wei Fang, Haizhong An, Xiangyun Gao, Huajiao Li and Shuepi Huang**. Modelling Urban Waste Treatment System by means of Emergy and System Dynamics: A Case Study of Beijing
4. **Francesco Calise, Simona Di Fraia, Adriano Macaluso, Nicola Massarotti and Laura Vanoli.** Assessment of a sludge dryer coupled with an ORC system powered by geothermal energy
5. **Krzysztof Sornek, Mariusz Filipowicz, Maciej ŻoŁĄdek, Radosław Kot and Małgorzata Mikrut.** Comparative analysis of selected thermoelectric generators operating with small scale heating appliances.

Panel 11. Energy related airborne emissions, air quality and monitoring tools.

Chaired by: **Fereidoon P. Sioshansi**, Menlo Energy Economics, CA USA, and **Marco Casazza,** University of Naples 'Parthenope'

1. **Massimiliano Lega, Dan Jaffe, Marco Casazza, Sergio Ulgiati.** Complex source components assessment: Criteria for 3D environmental scenario analysis in the case of an urban port area, Naples (S Italy)
2. **Xi Ji, Yixin Yao and Xianling Long.** What causes PM2.5 pollution? Cross-economy empirical analysis from socioeconomic perspective
3. **Tommaso Luzzati, Gianluca Gucciardi and Marco Orsini**. A multiscale analysis of the EKC for energy use and CO_2 emissions
4. **Angelo Facchini.** The urban metabolism of Lima: perspectives and policy indications for GHG emission reductions
5. **Giuseppina De Luca, Salvatore Fabozzi, Nicola Massarotti and Laura Vanoli**. The energy Planning of Pompei: a strategy to achieve a nearly zero greenhouses energy system city.

Panel 12. Innovative concepts and frameworks for effective energy strategies

Chaired by: **Francesco Gonella**, Ca' Foscari University, Venice, Italy and **Hossein Shahrokni,** KTH, Stockholm, Sweden

1. **Massimo Zucchetti and Raffaella Testoni.** Most advanced technological innovation as a part of simple solutions for the world energy problem.
2. **Corrado Giannantoni.** "Energy, Economy, Environment, Wellbeing". The Role of Formal Languages for Finding and Implementing Solutions.
3. **Enrique Ortega, José Maria Gusman-Ferraz, Mariana Oliveira, Ana Carolina Assis, Gilmar Barreto, Rosana Corazza, Paulo Fracalanza and Luciana T. de Almeida**. Energy and Wellbeing in Latin America: Political and Cultural issues
4. **Aram Mäkivierikko, Hossein Shahrokni and Olga Kordas**. Overcoming the Engagement Barrier in Demand-side Management with Social Influence
5. **Vasile Dogaru.** Segmentation of urban energy using Roegenian partial processes with borders
6. **Maddalena Ripa, Raúl Velasco-Fernández, Michele Manfroni and Mario Giampietro.** A closer look at national energy metabolism: multiscale integrated analysis of energy end uses

Panel 13. Biomass for energy and bio-based materials.

Chaired by: **Angelo Fierro**, Federico II University, Napoli, Italy and **Gabriella Fiorentino**, Parthenope University of Napoli, Italy

	1. **<u>Janis Abolins</u>.** Sustainability of the value chains of forest bio-economy and the added energy **2. <u>Elvira Buonocore</u>, Natasha Nikodinoska, Alessandro Paletto, Pier Paolo Franzese.** Life cycle assessment of wood-based bioenergy production: A case study in Northern Italy. **3. <u>Michelle M. Arnold</u>, Joseph A. Tainter and Deborah Strumsky.** Productivity of Innovation in Biofuel Technologies 4. **<u>Gabriella Fiorentino</u> and Sergio Ulgiati**. Towards an energy efficient chemistry. An assessment of fuel and feedstock switching. **5. <u>Paola Di Donato</u>, Annarita Poli, Barbara Nicolaus and Licia Lama.** Extremophiles' relevance for the production of second generation bioethanol **6. Ciro Florio, <u>Rosa Anna Nastro</u>, Fabio Flagiello, Mariagiovanna Minutillo, Domenico Pirozzi, Stefano Dumontet, Vincenzo Pasquale, Angelo Ausiello, Giuseppe Toscano and Elio Jannelli**. Biogas and Biohydrogen production from Solid Phase-Microbial Fuel Cell (SP-MFC) spent substrate: a preliminary study. ***<u>Panel 14. Developed and Developing economies in the energy market. New actors and new strategies.</u>*** *Chaired by:* **Catia Cialani**, Dalarna University, Sweden and **Tommaso Luzzati**, University of Pisa, Italy **1. <u>Kamia Handayani</u>, Yoram Krozer and Tatiana Filatova**. Assessment of the renewable energy expansion in the Java-Bali Islands, Indonesia **2. <u>Silvio Cristiano</u> and Francesco Gonella.** Building within environmental boundaries, between need and choice: low-energy, frugal technologies. Learnings from vernacular solutions – a Sudanese case study. 3. **<u>John Polimeni</u> and Raluca Iorgulescu.** An Analysis of Energy Poverty in Romania **4. Jari Kaivo-Oja and <u>Mikkel Stein Knudsen</u>.** Lessons from European Energy Research and Energy RIs: Towards a European Science of Research Organizations? 5. **<u>Catia Cialani</u> and Reza Mortazavi.** Econometric Estimation of Energy Demand 6. **<u>Kateryna Pereverza</u>, Oleksii Pasichnyi and Olga Kordas.** Strategic energy planning in different contexts: a modular approach to the participatory backcasting
21.00	***Guided tour to underground Napoli*** (Tunnel Borbonico, Vico del Grottone, 4, Napoli – close to Piazza Plebiscito)

Thursday 28th September

Session Chair: **Sanderine Nonhebel**, Center for Energy and Environmental Sciences, University of Groningen, The Netherlands	
9.00-9.45	***Keynote Lecture:*** Energy in wastewater treatment: consumption, benchmarking, performance assessment and improvement of efficiency **Nicola Massarotti and Laura Vanoli,** Department of Engineering, University of Naples 'Parthenope'
9.45-10.00	***Questions and comments***
10.00-10.45	***Keynote Lecture:*** **Energy and food, between complexity and fragility.** **Sanderine Nonhebel**, Center for Energy and Environmental Sciences, University of

	Groningen, The Netherlands.
10.45-11.00	***Questions and comments***
11.00-11.15	***Coffee break***
11.15-12.00	***Keynote Lecture:*** **Energy and Urban Systems: How smart, how big, how sustainable?** **Olga Kordas**, Royal Institute of Technology, Stockholm, Sweden
12.00-12.15	***Questions and comments***
12.15-13.00	***Summing up, Conclusions and Proposal for a final Workshop statement.*** **Sergio Ulgiati**, Parthenope University of Napoli, Italy
13.30	***Farewell buffet***

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Biennial International Workshop Advances in Energy Studies 2017

BIWAES 2017

PAPERS

Most advanced technological innovation as a part of simple solutions for the world energy problem

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Abstract

Energy studies are today interdisciplinary studies. They involve not just technical aspects, but also environmental, social and politic aspects. In this framework, an interdisciplinary approach to help solve energy issue through advanced technological innovations as a part of simple solution for the energy problem is considered. Two case studies were reported: the role of the fusion energy as new energy source and the methods to degrade polychlorinated biphenyls, synthetic compounds used in energy field, to reduce its environmental impact.

1. Introduction

In the twenty-first century, energy studies involve not just technical aspects, but also environment, society material science, and politics. In fact, the Energy issue is strictly connected to the issues of Water, Food, Health, and to the issue of resources availability and location (Zucchetti et al., 2016): these are systemic issues that require studies on local environmental and social aspects, not just technical ones.

From the purely technological point of view, two directions can be followed (Zucchetti and Testoni, 2017):

- Simple solutions that make it possible to reduce the growth of energy needs in developing countries, focusing on efficiency, savings and conversion, and that will lead to the reduction of social and geographical disparities in its availability and its use.
- Most advanced technological innovation, that aim to seek new energy sources and high-tech energy-intensive approach, in developed countries. In this direction, it is fundamental to take into account two guiding concepts: the equivalent of Einstein's mass-energy (e.g., nuclear fusion), and the imitation of energy production of living beings (e.g., artificial photosynthesis).

Four main actions can be pursued to face the energy issue (Zucchetti and Testoni, 2017):

- rationalize the use of energy;
- abandoning a development model based on endless growth;
- equalize the per capita consumption in the world;
- innovate and develop new energy sources.

In this work, two case studies applied at two different fields of technology will be addressed briefly in order to discuss the implementation of some of the above-mentioned actions. The first case study involves the contribution of nuclear energy in the framework of energy issue and the development of a new technology in the fusion nuclear field, Affordable Robust Compact (ARC) fusion reactor. One of the main innovative characteristics of this technology is its load-following capability. Instead, the second case study concerns the environmental impact of polychlorinated biphenyls (PCBs), that are synthetic compounds widely used in energy sector for dielectric fluids, heat transformer fluids, lubricants, etc. The use of irradiation techniques to degrade PCBs is presented in order to propose possible solution to reduce the environmental impact of these compounds.

2. Nuclear energy and the ARC fusion reactor

The role of nuclear energy in the field of development of new energy source is recognized by the world scientific community. However, an open debate on nuclear energy concerns the solution of the problem of radioactive waste, reinforcing nuclear safety and developing research into reactors of the future. In fact, nuclear energy is facing a crisis due to the lack of widely accepted solutions to some of its issues: radioactive waste management, health impact on population and workers in case of severe accident, nuclear proliferation, and effectiveness in solving the global warming issue.

On one side, the acceptance of fission nuclear energy by the public is quite doubtful: it will depend on the safe continuing operation of existing plants, the trends in energy demand, in particular electricity, and on the ability to meet a share of demand in a competitive way.

On the other side, nuclear fusion energy is seen as a candidate long-term solution, for developed countries: however, fusion should not follow the same path that lead to the technological difficulties causing fission energy public acceptance. Fusion energy is seen as a clean energy quest, that has important improvements, such as no NOx and COx emissions, no core melting risks, no proliferation and very low amount of radioactive waste. These improvements are also associate with the fact that fusion energy can be considered practically an infinite energy.

Most of the studies and experiments on nuclear fusion are currently devoted to the Deuterium-Tritium (DT) fuel cycle (Zucchetti and Testoni, 2017). This fuel cycle represents the easiest way to reach nuclear fusion in a plasma. However, it needs a reactor similar to that one used for fission energy. In particular, problems such as neutrons, radioactivity, radioactive waste, environmental accidental releases, characterize both fission and fusion reactor, even if these issues in fusion reactor have a lower impact than fission one. The two main projects based on the fusion technology are ITER and DEMO. A lot of concepts and designs have been investigated in the last decades: magnetic confinement fusion seems to be the faster way to reach the grid, and - among magnetic confinement fusion machine designs - tokamaks are the ones considered the most "reactor relevant". This pathway, arriving to DEMO (a demonstration reactor) through the previous construction and exercise of ITER (a world-shared fusion experimental tokamak now being built in France) appears to be quite a long and winding road to commercial fusion energy. Even if, the relatively slow pace of development of fusion research in the recent decades due for example to the delay in the ITER and DEMO programs, has moved fusion energy to a quite long-term option (Zucchetti, 2015; Freidberg, 2007).

However, fusion energy is one of the most challenging and complicated fields for Engineering and Physics. Many physics and technology questions need further development and research, such as plasma physics, magnets physics, reactor engineering, plasma-wall interactions, etc. Nuclear fusion energy has always been considered the ultimate response to the clean energy needs of the future. However, the goal of fusion energy connected to the grid is supposed to lie several years from now. Fusion scientists need to understand better not only plasma, magnetic physics and reactor engineering, but also dealing with the market competition, which always asks for more and cheaper energy. Because of all the above-mentioned obstacles, nuclear fusion seemed to be stuck for undetermined time.

In this general fusion framework, the advent of High Temperature Superconductors (HTS), additive manufacturing, new diagnostics and materials have unblocked research, leading to new scenarios and to a second generation of nuclear fusion reactors. In this context, PhD candidates of Massachusetts Institute of Technology (MIT) and MIT's Plasma Science and Fusion Center (PSFC) scientists and engineers began to design a new Affordable Robust Compact (ARC) fusion reactor, which meets its goal in a cheaper, smaller but even more powerful, faster way to achieve fusion energy (Sorbom et al., 2015).

ARC reactor (Fig. 1) is a tokamak conceptual design: it is the flagship of a new generation of fusion devices, which have the final goal of showing a new path to a clean, fast and cheap fusion energy connectable to the grid. Since it is just a device concept, which shows how far new technologies could lead fusion energy, its design is always changing and every new idea is applied and integrated to the design in order to see any type of possible improvement; this means that the tokamak is frequently upgraded to the newest technology known until the construction of a device based on this design will be committed, and beyond.

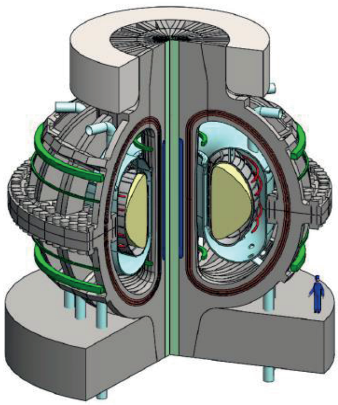

Fig. 1: The ARC reactor conceptual design (Sorbom et al., 2015).

ARC reactor is based on the new rare hearts HTS technology (REBCO), which allows the reactor to be smaller and thus cheaper; moreover, it shows a new concept for the cooling system, which is contemporarily the blanket and the tritium breeder. Finally yet importantly, the new concept of vacuum vessel, designed to be built using additive manufacturing technology is a promising improvement. All these innovations are inserted in a compact and easy to demount reactor design (Sorbom et al., 2015).

Now, these main characteristics of the ARC reactor are described. First, the idea of ARC's concept began when a new generation of superconducting materials became available on industrial scale. The most important innovation are its magnets: sets of toroidal field coils (TF) and poloidal field coils (PF) are made of Rare Earth Barium Copper Oxide (REBCO). This material shows a quite high critical temperature ~ 80K, which is almost twenty times higher than copper's critical temperature, and is able in a very thin tape to generate a magnetic field of tens of Teslas.

A second innovation integrated in this device is the approach to blanket, cooling system and tritium breeder all of them: a single material satisfies all functions done by those components. ARC shows a liquid blanket: its vacuum vessel is immersed in a tank filled with Lithium Fluoride and Beryllium Fluoride (FLiBe) molten salt. FLiBe works as coolant for the vessel and divertors carrying out thermal energy up to the heat exchangers it shields magnets and component from radiations and neutrons slowing them down and absorbing their energy. Since FLiBe is a mixture of Lithium and Beryllium, it works also as neutron multiplier and tritium breeder both, achieving a tritium breeding ratio of around 1.1.

Then, thanks to new manufacturing systems such as 3D printing, this tokamak is also designed to be quickly demounted and reassembled since the number of components is allowed to be very low. For instance, vacuum vessel and blanket tank are single-piece components imagined for additive manufacturing; this means no slices, and no days of work to change each of them. Toroidal field coils are designed to be opened on their upper side so tank, vessel, auxiliary and poloidal field coils can be dropped on their spot from the top leading to a very easy and quick way to assemble main components of the machine.

Finally, the most innovative characteristics of ARC, in our opinion, is the load-following capability. Since plasma can quickly change its power output, a load following power plant, based on the ARC concept, can be connected to a grid characterized by several other intermittent energy input, such as solar and wind based power plants. In this case, the ARC reactor could be not only the base-load energy producer, but also a load-following one, capable to cover peak requests and other plant shutdowns.

3. Radiation Induced Degradation of Polychlorinated Biphenyls (PCBs)

Polychlorinated Biphenyls (PCBs) (Tab. 1) are synthetic compounds, very stable, with high molecular weight, low vapor pressure, low water solubility, and high stability. They are widely used in the energy production sector – either in developed and in developing countries - for dielectric fluids, heat transformer fluid, lubricants, vacuum pump fluids, etc. Now banned in most developed countries, they are still widely used in developing countries (Robertson and Hansen, 2015; Jepson and Robin, 2016).

The widespread use of polychlorinated biphenyls in such applications presents a major environmental issue because of the toxicity and long lifetime of these compounds in ambient conditions. The method currently used to destroy most PCB containing materials is incineration. Two drawbacks characterize this method: it incinerates the medium along with the PCB, and it converts some of the PCB into more toxic materials, namely dioxins. For instance, in the US, currently a regulatory threshold of 50 parts per million of polychlorinated biphenyls has been established under the federal Toxic Substances and Control Act. Therefore, it is desirable to provide a method for the degradation of solutions contaminated with polychlorinated biphenyls, to a level below the regulatory threshold in a closed system to prevent the release of the PCBs into the environment. Additionally, it is desirable to provide a PCB destruction method that does not rely on the addition of chemicals to the PCB contaminated solution.

Table 3.1: Polychlorinated Biphenyls (PCBs) structure and properties

Chemical properties	Chlorinated aromatic hydrocarbons
	209 isomers
	tech. PCBs containing up to 80 isomers
Physical properties	High chemical and thermal stability (>1000°C)
	Low in flammability
	High heat conductivity
	High solubility in rubber
	High solubility in fat
	No solubility in water

Radiolytic degradation of PCBs is expected to overcome these problems (Omega Research Ass. Inc., 1986; Platzer et al., 1990). In general, it is known that gamma irradiation of chlorinated hydrocarbons in alkaline polar solvents results in the production of free radicals via chain dechlorination to the next less chlorinated species. The PCBs in organic solvents such as transformer oils may be reduced into benign inorganic chloride and practically non-toxic biphenyl, without formation of any dioxins. Such treatment leaves the solvents practically unchanged so that they can be recycled instead of incinerated. This approach may be adapted to remove PCBs in sediments and soils by combining it with extraction or other treatment methods.

Irradiation of PCBs in oil is not expected to lead to dechlorination by direct reaction of the solvated electrons with the PCB, because the oil contains substantial quantities of other aromatic compounds, which also react with solvated electrons very rapidly. PCB transformation occurs primarily through reductive dechlorination, forming lower chlorinated PCBs and biphenyl. Rates of PCB degradation are substantially higher in aqueous surfactant solutions than in diethyl ether and petroleum ether. This suggests that solubilizing PCBs in water using a surfactant prior to irradiation may provide a considerable improvement in contaminant degradation efficiency in comparison to using an organic solvent or irradiating PCBs directly in oil.

Beta-irradiation techniques for elimination of noxious and toxic chemical substances from industrial pollutants are proposed in this study. Ionising radiations are being widely used in industrial processes, especially in those with high technological innovation content and strong development rate. In particular, the use of beta radiations shares with gamma industrial irradiation most of the market. Beta-emitting radioactive sources may be used, while industrial application processes mainly use electron beams (EB) accelerators. Among the applications of EB, environmental technologies, which are a very well-developed application field, rely upon this basic principle: an industrial pollutant, either gaseous or liquid, is irradiated with beta particles in order to induce in it chemical transformations (or biological sterilisation) in such a way that the pollutant itself could be more easily treated with conventional techniques for its environmental processing, or it could be easily recycled. EB that are being used for industrial application have energies normally ranging from 100 keV to 10 MeV. Energies higher than 12 MeV are not recommendable, since this is the threshold for electron-induced radioactivity in the irradiated material. The EB power is ranging from 1 kW to 150 kW. The power obviously depends upon the quantity of material that has to be treated in the time unit. The technique that is being investigated uses an EB linear accelerator (Linac) with a 3 MeV electron energy. As far as the aspects dealing with the interaction of beta particles with matter, a model has been set up, in order to compute the efficiency of the irradiation process, depending upon different geometrical layouts. This efficiency depends upon the self-shielding effects in the irradiated material. Comparison with alternative techniques based upon chemical treatments, from the safety viewpoint has been carried out.

It has been demonstrated that a complete chemical destruction of PCB occurs with electrons of this energy. The activity has focused on the safety and environmental aspects, and also on the studies of interaction between beta particles and matter, applied to the proposed case. The demonstration of the technological feasibility of the proposal, together with its economical convenience, is the most important result: the application of the technique to eliminate PCB in both developed and developing countries has demonstrated to conveniently solve the question of destroying PCB-related waste generated in energy production.

Conclusions

Energy studies involve not just technical aspects, but also environment, material science, and politics. In this work, two case studies on advanced technological innovation as a part of simple solutions for the energy problem were reported. The first case study involves the contribution of nuclear energy in the framework of energy issue and the development of ARC fusion reactor. One of the main innovative features of this technology is its load-following capability. Since plasma can quickly change its power output, a load following power plant can be connected to a grid characterized by other intermittent energy inputs. In this case, the ARC reactor could be not only the base-load energy producer, but also a load-following one, capable to cover peak requests and other plant shutdowns. Instead, the second case study concerns the environmental impact of polychlorinated biphenyls (PCBs), that is widely used in energy sector for dielectric fluids, heat transformer fluids, lubricants, etc. The use of beta-irradiation technique to degrade PCBs is presented as one feasibility solution in order to reduce the environmental impact of these compounds, both from the technological point of view and from the economical convenience.

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Shale Gas for a Low Carbon Economy? The limitations we have to consider

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Abstract

After two years of low world gas prices and high fossil fuel production, and the commitment of president Obama of reducing carbon emission in the oil and gas sector, the victory of Donald Trump and OPEP's plans of curbing extraction seem to predict a new golden period for shale gas as a pillar in the energy security and economic stability of the US. The scientific community has devoted a number of efforts to study the impacts of shale gas production and use over the environment, the societies and the economies separately. However, for policy making, it would be more useful to analyze the trade-offs of different scenarios in the production and use of shale gas.

In this work, I use MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) to analyze the socio-ecosystem metabolism of the US and describe the trade-offs of shale gas development regarding its environmental feasibility, its social desirability and its economic viability.

I present three scenarios for 2025. First, a no change scenario where shale gas contributes the same share to the US energy mix as in 2016. Second, I test President Obama's commitment to cut methane emissions from the oil and gas sector to 45% below 2012 levels. Third, I test president-elect Trump's plan to "unleash" U.S. shale gas reserves using a scenario where Pennsylvania's shale gas extraction is increased by 100%.

The preliminary results show that the three regions in the feasibility-viability-desirability option space overlap slightly. Scenario 1 is likely to challenge energy security due to low supply of energy primary sources. Despite being the most desirable scenario regarding climate change, scenario 2 does not seem to be biophysically viable with the current energy technology and networks. Scenario 3 is also not completely desirable. While it seems to be able to ensure energy availability, it would not contribute to increase jobs in the announced numbers but it would increase the environmental impacts beyond current regulation limits.

Design of a Low-Carbon energy system for a new urban area in an industrial neighborhood

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Abstract

In the West of the City of Graz, in the area of a former brewery, a new urban quarter is going to be established that is oriented towards more sustainability, low carbon patterns and at maximizing the share of renewables in the energy system. The area lays in the industrial part of the City of Graz and is surrounded by different kinds of companies like steel, food, feed, chemical and machinery industry. As the City of Graz has decided to reduce its carbon footprint and to increase the share of renewables the challenge is to design the systems for energy supply und usage for 8,000 people accordingly. Since it is one of the main planning criteria for the district to have an “integrated” quarter, there is also the necessity to create an adequate number of jobs. Another important issue is mobility. The design intents to have less parking lots than flats. So public transport, cycle tracks and car sharing activities will play a paramount role.

From the energy point of view, there are several possibilities to supply energy to the new dwellings. We expect all new buildings to follow a low energy standard (yearly energy for heat ~ 35 kWh/m²). This is higher than what the European Building Directive asks for after 2020, but most of the investors will not be ready to go for such highly insulated solution already now. The concept worked out integrates internal energy sources like solar radiation, ground water and internal waste streams. More than this, the waste energy from some industrial plants in the surroundings can be utilized, since it is available in great amounts on a low temperature level. The technologies included in the analysis are solar thermal panels, photovoltaic modules, heat pumps, biogas plants and of course waste heat exchangers. For outside the area energy can be supplied. There is a district heating line passing by (high temperature supply line, low temperature return pipe), a gas pipe and electricity.

The analysis and simulation showed that theoretically it would be possible to supply all heat demand (heating, sanitary water, commercial use) through locally available renewable energy. This is not the case for electricity. Waste heat from industry plays a major role in the optimized system, when costs are taken into consideration. The analysis also showed internal optimization possibilities in the companies and several interaction possibilities between industry and living spaces.

1. Changed boundary conditions for urban energy systems

The structure of urban energy systems has changed substantially in the last years. Traditionally a small number of supply companies cared for a safe and cheap supply of electricity, gas, fuels and district heating. First costs for the connections to the grid were rather low and the companies made profit by selling energy. Environmental concerns accounted for local emissions only.

This has changed in the last years. National and international agreements ask for more renewable energy sources in the system (United Nations, 2015). The Directive 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings asks for Nearly Zero-Energy Buildings: *Member States shall ensure that: (a) by 31 December 2020, all new buildings are nearly zero energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings* (EU 2010). 'Nearly zero-energy building' means in this context a building that has a very high energy performance, as determined in accordance with Annex I of this directive. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

Taking this into consideration, we were faced with a challenge of designing an energy system for a newly to be developed district in the West of the City of Graz in Austria.

2. The area under investigation

The area to be developed is a former industrial area less than 1.5 km from the city center. On the basis of the solidarity between the City Planning Department (Stadtbaudirektion) of the City of Graz, the Graz University of Technology and the Federal State of Styria, the processing of the flagship project has been conceived. Main project-issue is the scientific work and the demonstration of the vision of the energy self-sufficient, CO_2- neutral city-district Graz-Reininghaus. With the Framework-Plan ECR an awareness-raising process towards energy-efficient and sustainable city-development has been stimulated. The environmental department of the City of Graz, ("Umweltamt der Stadt Graz") and the "Energie Graz" are providing additional professional input. If required, other experts and departments of the City of Graz will be involved into the project. The research team was composed of different institutes of the Graz University of Technology.

The size of the new urban quarter is about 100 ha and should be the residence of 8.000 to 10,000 people. According to the idea of an integrated neighborhood, there should be 8,000 jobs as well. The area will be connected to the city by a tramway and fast bike roads. Parking will be little; there will be less than one parking lot per flat, most of them underground.

The west of Graz has been the industrial part of the City and still is. Still there is a great number of industrial and commercial sites. They form the surroundings of the new Smart City quarter and influence the quality of life there in several ways.

Total Smart City Area in Graz: 396 ha

Smart Quarter: 49 ha

Investigated area Reininghaus: 96 ha

Don Bosco 35 ha

Figure 1: The area under consideration

3. Energy sources, nets and technologies

The city administration as set out a number of challenges for the energy concept:

- Energy- self-sufficiency for the City- district is the main aspiration. (Project goal)
- Supply security has to be guaranteed at any time
- Modular building structure of the city- quarters for the future (concept for decades)
- Economical, political and legal framework conditions are to be taken into account - dialogue between stakeholders!
- Best possible realization (results from the energy supply concepts to be put into practice)

The energy sources under investigation are several. Inside the quarter, there is solar radiation, wind, groundwater, biomass (from organic waste and from greens), geothermic energy and waste heat from industries and commercial activities including cooling installations. Around the quarter, there is energy from the district heating system (supply and return pipe), natural gas, electricity and industrial waste heat.

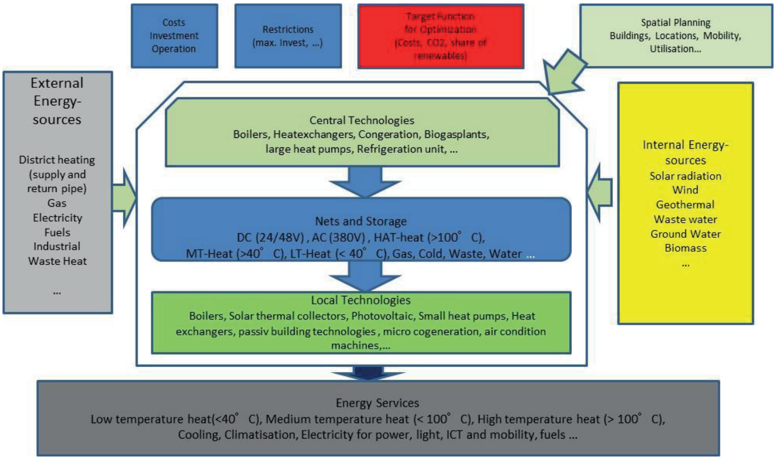

Figure 2: The urban energy system and its boundaries

It was one of the optimization challenges to link the energy nets with suitable technologies.

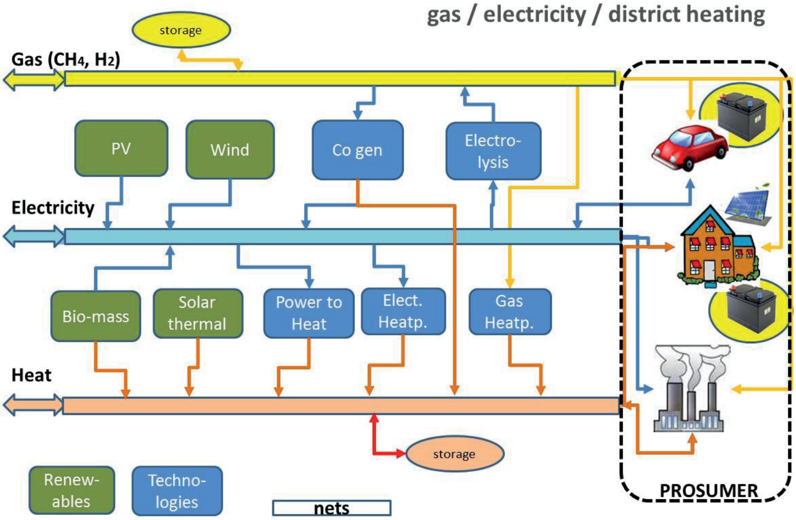

Figure 2: The INTERNET of Energies

The energy demand has been determined by the needs of the buildings (heating, cooling), the people (sanitary hot water, electrical devices), the commercial activities and mobility. For the thermal quality of the buildings, two scenarios have been taken under consideration: energy efficient houses (now standard in Austria OIB ~30 kWh/m²a) and near zero energy houses (NZE<18 kWh/m²a).

4. System design and optimization

4.1 Renewable energy potential

According to the request for an energy system based 100% on renewable energy, an estimation of the potentials has been carried out. Basis for this was:

- the estimation of the energy needed for heating, cooling sanitary water and electricity for the buildings planned on the basis of two different energetic standards (present OIB[1]: low energy, future NZE: near zero energy)
- the calculation of the available renewable energies (solar radiation, biomass, waste water, soil) including realistic efficiencies of know technologies (collectors, PV, heat pumps, biogas, …). There is no wind and surface water in the area investigated.
- For sanitary hot water we estimated 2 kWh/person/day.

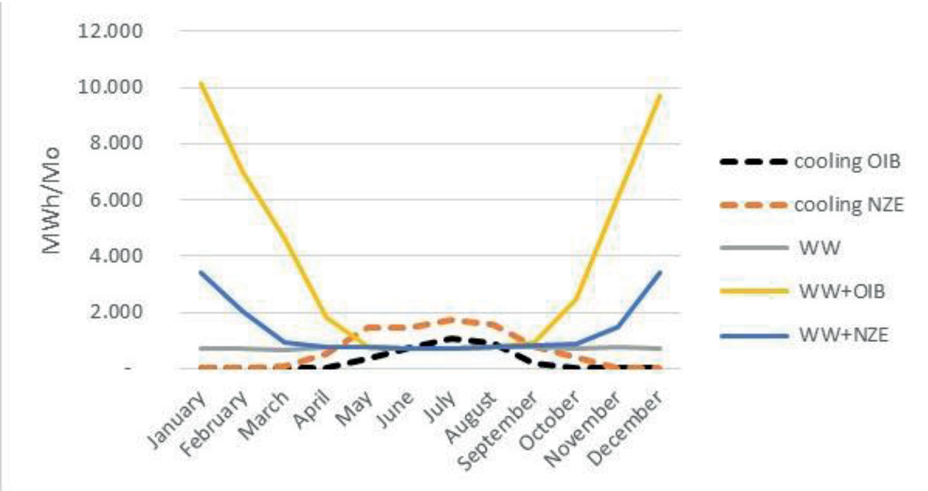

Figure 3: Yearly profiles of heat demand

These demand profiles were compared to the available renewable energies. The calculation showed that for Nearly Zero Energy houses, there is enough thermal energy all over the year. For the present standard in Austria, there is a need for external energy two months in winter. The main sources in winter are ground water and surface collectors.

[1] OIB = Austrian Institute for Building Research

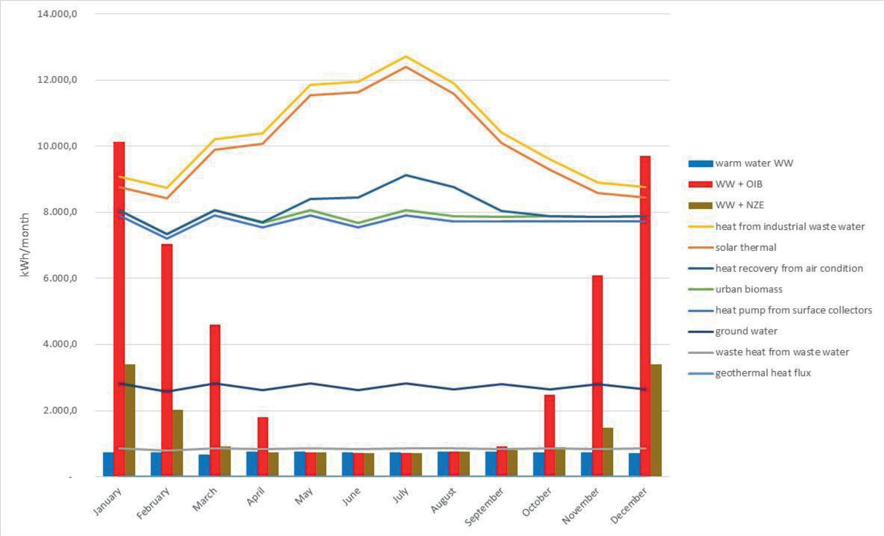

Figure 4: Demand (bars) versus sources (lines cumulated) over year

More calculations in the project showed that the electricity demand could not be covered from sources onsite, especially not if heat pumps are installed.

4.2 Process network Synthesis

Process Network Synthesis (PNS) is a method to optimise systems of material- and energy flows. Methodical background is the p-graph method using combinatorial rules (Friedler et al. 1996). For urban and regional planning the software tool PNS Studio is used to find sustainable technology systems (Narodoslawsky et al: 2008). Starting point of a PNS analysis is to set up a maximum structure. Hereby all available raw materials and resources (including waste heat flows) can be defined as well as the technology network which can convert them either to intermediates which can be used in other processes or to products which can be sold on the market. Capacities of technologies as well as availability, amount and quality structure of materials are user-defined. Moreover time bound availabilities of resources, the specific demand of products, mass- and energy flows, investment and operating costs of the whole infrastructure, cost of raw materials, transport and selling prices for products must be defined.

Result of the PNS is the output of a maximum structure. The method is carried out with PNS Studio. The programme creates an optimum structure, which contains an optimum technology network. For this application, the generation of the economically most feasible technology network is in the centre of consideration by setting the revenue for the whole system as target value.

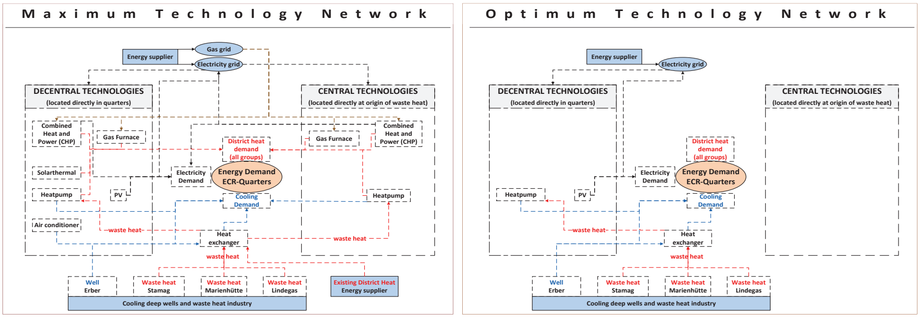

Figure 5: Maximum and optimum technology network

With Process Network Synthesis (PNS) a maximum structure was generated. This maximum structure contains a variety of possible technologies which can provide energy needed. In each of the quarters of the case study area fossil gas driven CHP units and gas furnaces, solarthermal plants, heat pumps with or without integration of waste heat, photovoltaic power plants and air conditioner can provide heat, domestic hot water, cooling energy and electricity needed.

5. Conclusions

For urban quarters with the building standard as demanded in the European Building Directive, heating with local renewable resources is possible. Electricity in dense areas has to be imported from the grid. For areas with a low density, electricity might be generated onsite as well, but storage has to be managed.

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Environmental evaluation of different techniques for concrete mixing

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Abstract

In this study emergy analysis, an environmental valuation method was applied to concrete mixing with the purpose of evaluating its dependence on non-renewable natural resources. Three concrete mixing techniques, industrialized, semi-industrialized and manual, were evaluated based on quality control. The quantity of environmental resources used in production was measured in terms of equivalent solar energy. The resulting transformities were compared to show that emergy analysis is sensible to local context and the limits of the reference system. The results obtained show that concrete mixing is highly dependent on external resources. Semi-industrialized concrete was found to be the most sustainable.

Keywords: emergy analysis; environmental accounting; sustainability; transformity; concrete.

1. Introducción

In recent years, economic development has generated negative environmental consequences. There is now a pressing need to develop management tools that can help minimize environmental impacts. In the construction industry and in the industrial sector in general, integrating environmental criteria in the design and manufacturing of products can significantly reduce the environmental impact of these products throughout their life cycle- from the extraction of raw materials for their manufacturing all the way to their final disposal.

The Mexican Association of Independent Concrete-makers (AMCI) estimated, for the year of 2015 an eight percent growth in the sector, double the estimate of 2013, driven by federal infrastructure and housing development projects in the country. The production of concrete in Mexico stands presently at 32 million m^3 annually. Production with existing infrastructure could be 50 million m^3 annually.

Accordingly, this study refers to the intensive use of mineral non-renewable resources and fossil fuels for the extraction of inert aggregates (sand and gravel), the use of water, the production of cement for concrete mixing and, in particular, evaluates the quantity of inflows of environmental resources in the production process. Concrete mixing was evaluated as a study case, considering the standard process for the manufacturing of Composite Portland Cement 30R. In comparison with data and values calculated previously, this study shows that emergy analysis is particularly sensible to context limits and reference systems (Brown y McClanahan, 1992; Buranakarn, 1998; Björklund et al., 2001; Brown y Buranakarn, 2003; Pulselli et al., 2008). An ecological accounting method was implemented in the concrete mixing techniques included in this study with the objective of providing better comparing each technique's sustainability.

2. Methodology

2.1 Emergy analysis

Emergy analysis evaluates inflows and outflows of energy and materials in common units (solar emjoules, abbreviated as seJ) that allow the analyst to compare environmental and financial aspects of the system. Based on this unit, emergy can be defined as the quantity of solar energy used, directly or indirectly, to produce a particular good or service (Brown et al., 2004). In other words, emergy is the "energy memory" that is used along a sequence of processes to obtain a good or service. Solar transformity is the solar emergy required to generate a Joule of a service or a product. Its units are the solar-emjoule/Joule (seJ/J).

Taking the region into account, the use of nonrenewable resources by the construction industry was evaluated by means of an emergy analysis. This procedure followed a top to bottom approach beginning with an emergy analysis of the country (Mexico), then the state of Chiapas, the municipality of Tuxtla Gutierrez, and finally at the level of each technique studied. The objectives of this study are presented as follows:

- Provide a methodology that evaluates the costs and benefits of the concrete mixing.
- Compare different concrete mixing techniques using emergy indexes such as the Emergy Investment Ratio (EIR), Emergy Sustainability Index (ESI), and Transformities.

According to the information collected in the study case zone and to the present knowledge of the field of emergy analysis, three techniques were identified for the production of hydraulic concrete. In addition, the local construction industry referred to f´c=24.53 MPa concrete as the most used in the zone.

For the study of the alternatives related to concrete mixing three techniques, 1) industrialized 2) semi-industrialized and 3) manual, were selected and evaluated by means of an emergy analysis. The comparison was done using the emergy indexes obtained for each case study in the city of Tuxtla Gutierrez, Chiapas, Mexico, to determine the environmental viability of each of these options. The unit of evaluation was the cubic meter.

The following specifications were considered for each technique:

- Industrialized technique: This technique can be distinguished from the other two techniques by the use of heavy machinery, such as concrete plants, mixing trucks and front loaders, with eight workers required for the whole production process.
- Semi-industrialized technique: The main characteristic of this technique is the use of simple machinery (portable drum mixer) combined with manpower (a group of about ten workers). Helped by a gasoline powered concrete mixer, this technique is used for the mix of moderate volumes (no more than 45 m^3 by group of workers).
- Manual technique: This technique uses about fifteen workers with moderate skills, including two technicians, one of them directing the workforce and the other supervising quality. With help of simple tools and without the use of fuels, electricity or mechanical energy, this method is generally employed for small volume production (no more than 10 m^3 per group of workers).

For this study, the transformities for the inert aggregates (gravel and sand), cement and water were calculated for the city of Tuxtla Gutierrez, Chiapas, Mexico. The valuation was done taking into account an annual production of 70,000 m^3 for industrialized concrete, and a daily production for semi-industrialized and manual concrete of 45 m^3 and 10 m^3 respectively. The transformity of cement was based on the annual production of 2,190,000 tons of the local cement plant. The transformity employed for sand corresponds to the extraction area of the Santo Domingo River located in the municipality of Chiapa de Corzo, Chiapas, at a distance of 30 km from the city of Tuxtla Gutierrez, Chiapas. The crushed gravel was extracted from the quarry located in the neighborhood of Plan Chiapas in the municipality of Chiapa de Corzo where it borders with the municipality of Tuxtla Gutierrez.

The emergy indexes employed in the study were: the EIR, calculated as the relationship between contribution from the economy (F) and nature (I), which is adimensional. The ESI shows the contribution of the natural environment, that is to say, the energetic work that the ecosystems do to generate processes for the environmental load. This value was calculated dividing the contribution of nature by the environmental load.

Finally, the calculated emergy values of concrete in this study were compared with those in previous emergy studies with the objective of showing how emergy analysis is sensible to local context and the limits of the reference system.

3. Results and discussion

This study allowed a comparison between the different concrete mixing techniques selected, using emergy indicators such as EIR and ESI. The emergetic attributes of each system were quantified and used as indicators of the characteristics of each technique. For the evaluation of each alternative, the concrete considered was f´c= 24.53 MPa. These proportions were obtained at the Concrete Technology Laboratory at the Engineering Deparment of the Universidad Autónoma de Chiapas, for the study cases of manual and semi-industrialized techniques. The corresponding indicators for industrialized concrete were obtained from a concrete factory in the city of Tuxtla Gutierrez, Chiapas, Mexico.

The diagram of energy flows interacting within the concrete mixing system shows (Figure 3.1) renewable and nonrenewable resources as well as the energy acquired by inputs (materials, services, manpower). Based on the flow diagrams, an emergy analysis was performed for each alternative and is presented

in Tables 3.1, 3.2 and 3.3. For each case, the emergy of concrete mixing was based on the following supplies: raw materials, transportation, equipment and machinery, fuels, manpower, maintenance and insurance.
The total emergy consumed by each mixing technique was of 5.9 E15 seJ, 5.87E15 seJ and 8.32E15 seJ, with manual means, semi-industrialized and industrialized, respectively as can be seen on Tables 3.1, 3.2 and 3.3. In the mixing of industrialized concrete, 98.14% of the total emergy is materialized in the sedimentary natural cycles of construction materials. Machinery accounts for (0.084%), fuel for (1.00%) and manpower for (0.24%). With semi-industrialized concrete, 99.44% is materialized during the sedimentary natural cycles of construction materials. Equipment and tools account for (0.045%), fuels (0.022%) and manpower (0.076%). Finally, concrete mixed by manual means shows that 98.02% of the total emergy is materialized in the natural sedimentary cycles of the construction materials. Equipment and machinery account for (1.47%), and manpower for (0.50%).

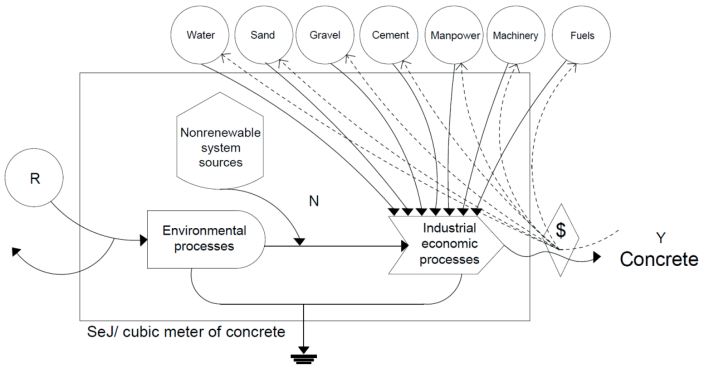

Figure 3.1: Simplified diagram of energy flows in the production of concrete.

Table 3.1: Emergy analysis of the production of industrialized concrete

No.	Description	Units (unid/m³)		Transformity (seJ/unid)	Emergy (seJ/m³)	References
	MATERIALS					
1	Cement	4.00E+05	g	3.61E+09	1.44E+15	*
2	River Sand	1.07E+06	g	3.29E+09	3.53E+15	*
3	Crushed gravel T.M.A. 3/4"	1.42E+06	g	2.24E+09	3.19E+15	*
4	Water	2.51E+05	g	3.27E+06	8.19E+11	*
5	Diesel	1.08E+08	J	6.60E+04	7.13E+12	Doherty et al, 1994
6	Lubricants	3.21E+05	J	6.60E+04	2.12E+10	Doherty et al, 1994
7	Electric power	2.76E+08	J	2.77E+05	7.63E+13	Odum, 1996
	PLANT AND MACHINERY					
8	Concrete doser	1.86E+02	g	6.70E+09	1.25E+12	Doherty et al, 1994
9	Cement Silo	8.06E+01	g	6.70E+09	5.40E+11	Doherty et al, 1994
10	Aggregate hopper	5.58E+01	g	6.70E+09	3.74E+11	Doherty et al, 1994
11	Conveyor belt	3.10E+01	g	6.70E+09	2.08E+11	Doherty et al, 1994
12	Cement weighing machine	2.23E+01	g	6.70E+09	1.50E+11	Doherty et al, 1994
13	Aggregate weighing machine	3.47E+01	g	6.70E+09	2.33E+11	Doherty et al, 1994
14	Water doser	2.48E+01	g	6.70E+09	1.66E+11	Doherty et al, 1994
15	Front loader	4.30E+02	g	6.70E+09	2.88E+12	Doherty et al, 1994
16	Mixing truck	1.14E+02	g	6.70E+09	7.64E+11	Doherty et al, 1994
17	Dump truck	5.95E+01	g	6.70E+09	3.99E+11	Doherty et al, 1994
	SERVICES					
18	Manpower	4.19E+06	J	4.77E+06	2.00E+13	Guillén, 1998
19	Maintenance and insurance	9.46E-01	$	4.59E+13	4.34E+13	*

*Transformity calculated for this study **Y = 8.32E+15**

Table 3.2: Emergy analysis of the production of semi-industrialized concrete

No.	Description	Units (unid/m³)		Transformity (seJ/unid)	Emergy (seJ/m³)	References
	MATERIALS					
1	Cement	4.02E+05	g	3.61E+09	1.45E+15	*
2	Sand	7.25E+05	g	3.29E+09	2.38E+15	*
3	Crushed Gravel T.M.A. 3/4"	9.04E+05	g	2.24E+09	2.02E+15	*
4	Water	2.33E+05	g	3.27E+06	7.60E+11	*
5	Gasoline	1.92E+07	J	6.60E+04	1.27E+12	Doherty et al, 1994
6	Lubricants	3.33E+04	J	6.60E+04	2.20E+09	Doherty et al, 1994
	EQUIPMENT AND TOOLS					
7	Wooden shovel handle	3.82E+03	g	6.79E+08	2.59E+12	Odum, 1996
8	Spoon shovel with metallic handle	8.77E-01	g	3.16E+09	2.77E+09	Bargigli et al, 2003
9	Plastic container with 19 liters capacity.	1.73E+00	g	8.57E+04	1.48E+05	Brown et al, 2003
10	Portable mixer with 2 sacks capacity	7.42E+00	g	6.70E+09	4.97E+10	Doherty et al, 1994
	SERVICES					
11	Manpower	9.30E+05	J	4.77E+06	4.44E+12	Guillén, 1998
12	Maintenance and insurance	6.36E-05	$	4.59E+13	2.92E+09	*

*Transformity calculated for this study **Y = 5.87E+15**

Table 3.3: Emergy analysis of the production of concrete by manual means

No.	Description	Units (unid/m³)	Transformity (seJ/unid)	Emergy (seJ/m³)	References
	MATERIALS				
1	Cement	4.02E+05 g	3.61E+09	1.45E+15	*
2	Sand	7.25E+05 g	3.29E+09	2.38E+15	*
3	Crushed gravel T.M.A 3/4"	9.04E+05 g	2.24E+09	2.02E+15	*
4	Water	2.33E+05 g	3.27E+06	7.60E+11	*
	EQUIPMENT AND TOOLS				
5	Wooden shovel handle	1.29E+05 g	6.79E+08	8.76E+13	Odum, 1996
6	Spoon shovel with metallic handle	2.96E+01 g	3.16E+09	9.35E+10	Bargigli et al, 2003
7	Plastic container with 19 liter capacity.	1.17E+01 g	8.57E+04	1.00E+06	Brown et al, 2003
	SERVICES				
8	Manpower	6.28E+06J	4.77E+06	3.00E+13	Guillén, 1998

*Transformity calculated for this study **Y = 5.98E+15**

The EIR value of industrialized concrete is higher when compared with the same value for semi-industrialized concrete and concrete produced by manual means. The value stands at 10,161 for industrialized concrete, at 7,724 for semi-industrialized concrete and at 7,867 for concrete mixed by manual means. This value suggests a weak competitive capacity due to the instability of external sources of materials. Figure 3.2 shows a comparison of the EIR for the three different techniques.

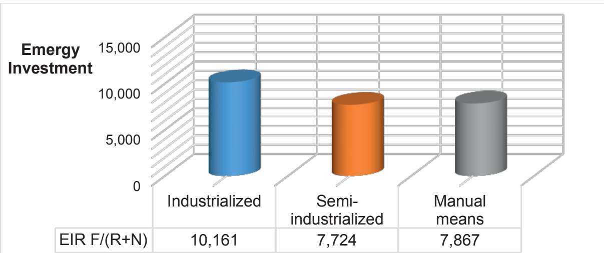

Figure 3.2: Emergy Investment Ratio of concrete mixing.

The ESI indicates the contribution of the natural environment, meaning that the energy work that is done by ecosystems to generate processes that act upon the environmental load. According to Brown and Ulgiati (2004), ESI values inferior to 1 indicate systems that consume resources and are associated with highly developed, consumption-oriented economies. The values reported in this study indicate that semi-industrialized concrete (0.000129) has a higher ESI value than that of concrete produced by manual means (0.000127) and industrialized concrete (0.0000984). This means that semi-industrialized concrete is the one that impacts environmental equilibrium to a lesser degree, and is therefore more sustainable for the environment than industrialized concrete and concrete produced by manual means. In relation to this index it is important to note that the main difference between semi-industrialized (4.44E+12) and manual production (3.00+13) is the manpower employed. Figure 3.3 shows a graphic comparison of the ESI results obtained for each alternative.

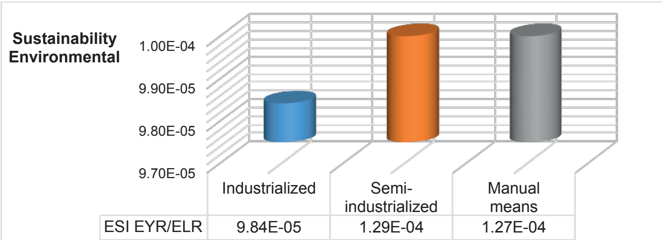

Figure 3.3: Sustainability in the production of concrete

With relation to other studies conducted in reference to the mixing of industrialized concrete, the following significant differences were found:
In Bjorklund et al (2001): the authors used solar transformity values in a national context. For example, the transformity of electricity is very specific, because it was evaluated according to production processes in Sweden, which includes nuclear energy (33%- here represented with the transformity of median world electric production), and hydroelectric energy (66%). In the present study, the emergy evaluation of cement production is not considered in the whole production process, and this represents an important approximation. In regards to the main supplies used in concrete mixing, the present study only considers the use of limestone, electricity and petroleum, while other inputs such as transport, packaging and services like manpower machinery and fuel were not evaluated. Electricity and manpower were evaluated by means of an emergy/money relation.
In Buranakam (1998), specific emergy was evaluated for the United States. The analysis included an evaluation of highways, vehicles and infrastructure used, taking into account the whole national transportation system. The author calculated the total length of national highways and their production process (materials, energy, manpower and other services), taking into account the annual cost of construction. This value (in seJ/km) was divided by the percentage of buses in relation to the total weigh of vehicles (cars, buses, trucks, and others). The same was done with railroads and maritime services (boats). In general, the useful life of highways, vehicles and all relevant infrastructures was not taken into account. Manpower and other services were evaluated using an emergy/money relation.
In the work of Brown and Buranakam (2003), the emergy evaluation was done based in Buranakam 1998, and it took into account the different stages in the use of materials, demolition and reuse. Accordingly, their analysis had to do with process inputs that had to do with specific procedures. The present work had the objective of determining the transformity of concrete, from its origin, to its use in the construction of buildings- excluding the disposal stage.
Similarly, Brown and McClanahan (1992) evaluated the specific emergy of Thailand with reference to the energy sources available at the local level. This analysis was carried out in 1992, using data from 1983. The emergy analysis was very simplified in comparison to the one in the present study due to the fact that the authors considered some problems such as material flows, petroleum and electricity as energy flows and other goods and services, this last one evaluated in terms of money flow (by means of an emergy/money relation).
On the other hand, Pulselli et al. (2008) centers his attention on the production process of the Italian cement and concrete industry. Most the values of the transformities in the study were evaluated in the U.S.A. The authors carried out an evaluation of a specific process taking into account a specific amount of 23 tons of concrete and its transportation to the construction site. In the selection of this system they consider some insignificant factors such as the evaluation of the total national transportation infrastructure (highways and other services). Figure 3.4 compares the transformities of concrete obtained by the authors previously cited and compares them with the results obtained in this work.

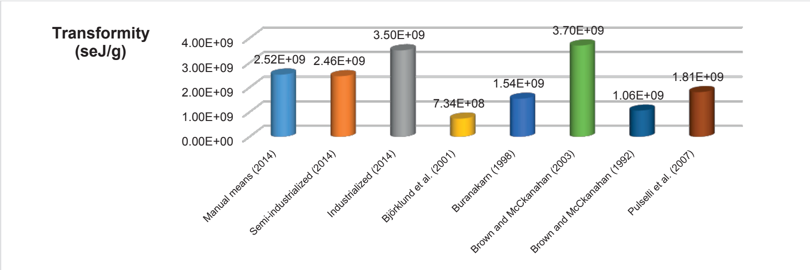

Figure 3.4: Comparison of the transformities of concrete.

4. Conclusions

The emergy method allowed for an analysis that considers the relationships between natural systems and anthropic activities and helps us look for strategies that are ever more sustainable.

The EIR was evaluated as an indicator of sustainability by measuring dependency on local or external sources. It was demonstrated that concrete mixing processes depend to a high degree in supplies obtained from outside the system (emergy input from imports).

The ESI was employed as a measure of the contribution of the system hierarchically higher to the production of the system by load unit of itself. The results show that semi-industrialized concrete (1.29E-4) is more sustainable than concrete manufactured by manual means (1.27E-4) or by industrial processes (98.4E-4).

Emergy analysis provides a way to measure the sustainability of concrete mixing techniques based on quality control in terms of energy investment. Many units of low quality energy are used to provide high quality energy (high Transformity). Energy is materialized by means of a chain of transformative processes and its memory is conserved by the production structure.

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“Energy, Economy, Environment, Wellbeing”
The Role of Formal Languages for Finding and Implementing Solutions

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Abstract. The paper aims at showing that the problems concerning the aspects mentioned in the title can better be analyzed by focusing on the formal languages adopted to describe them.
This is because any formal language is always the faithful “reflex” of the subjacent mental categories aprioristically adopted to describe the surrounding world. At the same time, the recognized expressive capacity of any formal language decisively influences the way of thinking, decision making and acting.
Up to know all the aforementioned aspects have usually been dealt with in terms of Traditional Differential Calculus (TDC), which however presents some unsolvable and/or intractable problems and, in some cases, it offers solutions characterized by a “drift” (with respect to experimental results), which often represents a “symptom” of possible “side effects”.
A different formal language, however, is now contextually possible. It is precisely that which emerges from the original thermodynamic approach proposed by Boltzmann and Lotka and, afterwards, much more deeply developed by H. T. Odum. A new scientific approach that has more recently led to a formal language termed as Incipient Differential Calculus (IDC).
The different solutions obtainable by adopting the two distinct formal languages, although with reference to the same problems, will be illustrated through the following ostensive examples: the research for equilibrium conditions in a free-market economy, the development of renewable energy sources, climate change forecasts, and some problems related to human health (for instance, new oncological therapies).
The paper concludes by asking a basic question: “Where are we going?”
In this respect the paper delineates three possible answers: i) a generalized persistence in the traditional formal approach (TDC); ii) some occasional adoptions of the innovative IDC approach; iii) more probably it may be expected the adoption of both approaches at the same time, so as to choose the optimal solutions on the basis of the corresponding experimental results.

1. Introduction. The fundamental role of formal languages

As already anticipated in the Abstract, *any* formal language plays a fundamental role because of two different, albeit strictly related reasons. On the one hand, in fact, any formal language is always the faithful “reflex” of the subjacent mental categories aprioristically adopted to describe the surrounding world. On the other hand, and at the same time, the recognized expressive capacity of any formal language decisively influences (or rather “guides”) the corresponding way of thinking, decision making and acting.
Let us then start by considering the two different formal languages that, at present, can be recognized as being the most known and adopted.

2. The two most known scientific formal languages

The scientific formal languages we are referring to are, on the one hand, the *Traditional Differential Calculus* (TDC), widely adopted in Modern Science and, on the other hand, the *Incipient Differential Calculus* (IDC), which originates from the theory of Self-Organizing Systems.
Let us first consider the *Traditional Differential Calculus* (TDC), which strictly pertains to the *Traditional Scientific Approach* and deeply characterizes all Modern Science.

2.1 The Traditional Differential Calculus (TDC)

As is well-known, Modern Science is characterized by a persistent ascendancy toward ever more general Physical Laws and Principles.
However, before any formulation of a single hypothesis or a physical theory, Modern Science (let us say, from Newton on) adopts three fundamental *pre-suppositions* (see the left hand side of Tab. 1 (Giannantoni, 2016)): the *causality principle* (also termed as “efficient causality”), *classical logic* (also termed as “necessary logic”), and *functional relationships* (between the various parts of any System analyzed).

On the basis of such fundamental presuppositions, Modern Science develops a strictly conform consequential *formal language*, that is the *Traditional Differential Calculus* (TDC), which is based on the well-known concept of *derivative* (of any order *n*):

$$(\frac{d}{dt})^n f(t) = \lim_{\Delta t \to 0} \left(\frac{\delta - 1}{\Delta t} \right)^n f(t) \qquad (1).$$

On the basis of such a formal definition, Modern Science progressively ascends toward ever more general Physical Laws and Principles, which lead to the conclusion that: "*Every System is a mechanism*" (see Tab.1).

Such a conclusion, however, although confirmed by experimental results, it is an assertion that can be considered as being valid *only* from an *operative* point of view, but not from an *absolute point of view*. This is because "necessary logic" (which is adopted as a second basic presupposition of such a scientific approach) does not admit any form of "*perfect induction*".

In fact, as synthetically illustrated in Tab. 1, in the strict context of "necessary logic":

i) after having formulated a single or more hypotheses (such as in the case of a Theory);
ii) after having formalized them in an appropriate formal language (faithfully conform to the three above-mentioned basic presuppositions);
iii) after having drawn the consequential conclusions
iv) and after having also obtained experimental confirmations of the previous formal conclusions;
v) it is impossible, *in any case whatsoever*, to assert the *uniqueness* of the *inverse* process. That is: it is impossible to show that the hypotheses adopted are the *sole* and *unique* hypotheses capable to explain those experimental results.

This is precisely because of the *absence*, in the context of "*necessary*" logic, of any form of a *perfect induction*.

In fact, only in the presence of a *perfect induction* it would be possible to assert the *uniqueness* of the *inverse* process and, consequently, to transform the adopted hypotheses into an *absolute* perspective.

This means that Modern Science, precisely because based on *necessary logic*, should always be "open" to recognize that *there always exist* many other *possible* Approaches (in principle *infinitive*) capable to interpret the same experimental results.

2.2 A new formal language that originates from the *phenomenological* description of Self-Organizing Systems

After having synthetically recalled the basic characteristics of Modern Science and its corresponding formal language, we can now analyze the fundamental properties of a New Scientific Perspective, which leads to the introduction of the *Incipient Differential Calculus* (IDC). The fundamental properties we are referring to are synthetically indicated in parallel (for a better comparison) in the right hand side of Tab. 1.

Basic Presuppositions	***"Emerging Quality"*** **of Self-Organizing Systems**
1) causality principle (efficient causality) 2) classical logic (necessary logic) 3) functional relationships	1') Generative Causality 2') Adherent Logic (Emerging Conclusions) 3') Ordinal Relationships
d/dt is the corresponding formal translation $f(t)$ represents a *functional relationship*	**Development of an appropriate Language** - L. Boltzmann, A. Lotka - H. T. Odum: Emergy Algebra and M. Em-P. P. - Further developments in transient conditions - Introduction of the "Incipient" derivative $\tilde{d}/\tilde{d}t$
- **Thermodynamic Principles (1st , 2nd, 3rd)** **- Physical Laws (specific for each Discipline)** **Every System is a "Mechanism"** **Hypotheses** ↓ **Mathematical Formalization** ↓ **Conclusions** ↓ **Confirmation by experimental results**	**The Maximum Ordinality Principle** **- is applicable to *any* Field of analysis: *non-living* Systems, *living* Systems, "*thinking*" Systems (e.g. Human Systems)** **- at *any space-time scale* and in *variable conditions*** **- it also offers a *more appropriate* description of any given System and its surrounding habitat** **Every System is a "Self-Organizing System"**

Tab. 1 - Synoptic comparison between the basic presuppositions of the two differential formal languages and their main corresponding fundamental characteristics

Such a New Scientific Perspective is based on the *phenomenological* "Emerging Quality" of Self-Organizing Systems (Giannantoni, 2016). This represents the fundamental aspect that leads to the adoption of the corresponding *new mental categories*.

In fact, the expression "*Emerging Quality of Self-Organizing Systems*" refers to the fact that Self-Organizing Systems always show an unexpected "*excess*" with respect to their phenomenological premises. So that they usually say: "*The Whole is much more than its parts*".

Such an "excess" can be termed as *Quality* (with a capital Q) because it cannot be understood as being a simple "property" of a given phenomenon. This is because it is *never reducible* to its phenomenological premises in terms of traditional mental categories: *efficient causality*, *logical necessity*, *functional relationships*.

This evidently suggests a *radically new* gnoseological perspective, which corresponds to recognize that: "*There are processes, in Nature, which cannot be considered as being pure* "*mechanisms*".

This also leads, *in adherence*, to the adoption of "*new mental categories*"[1] and, correspondently, to the development of a completely *new formal language*, so that the description of Self-Organizing Systems might result as being faithfully conform to their phenomenological "Emerging Quality".

2.2.1 The Progressive Development of an appropriate Formal Language based on the new concept of "Incipient Derivative"

Self-Organizing Systems and their "emerging properties" began to be studied by L. Boltzmann toward the end of XIX century (Boltzmann, 1886). Several other Authors (e.g. A. Lotka) dealt with such a theme (Lotka, 1922a,b, 1945). However, Self-Organizing Systems received the most significant contribution by H.T. Odum, by starting from 1955 on (Odum, 1994a,b,c).

All these studies led us to recognize that the "Emerging Quality" of a Self-Organizing System can appropriately be represented by means *a new concept of derivative*, the "Incipient Derivative", defined as

$$\left(\frac{\tilde{d}}{\tilde{d}\,t}\right)^{\tilde{q}} f(t) = \underset{\tilde{\Delta} t:0\to 0^+}{\tilde{Lim}} \circ \left(\frac{\tilde{\delta}-1}{\tilde{\Delta} t}\right)^{\tilde{q}} \circ f(t) \qquad \text{for} \quad \tilde{q} = \tilde{m}/\tilde{n} \qquad (2).$$

Such a definition, in fact, clearly shows that the concept of "*Incipient Derivative*" cannot be understood as an "operator", like the traditional derivative (d/dt). In fact it could better be considered as being as a "*generator*". This is because it describes a Process in *its same act of being born* (Giannantoni, 2001a,b, 2002, 2004a,b, 2006, 2008a, 2010a).

In this respect, the "Incipient Derivative" is exactly the *formal concept* that allowed us to reformulate Odum's Maximum Em-Power Principle into a more general form, that is, as the Maximum Ordinality Principle (M.O.P.) (Giannantoni, 2016). A Principle which (see right hind side of Tab. 1) is applicable to *any* Field of analysis: *non-living* Systems, *living* Systems, "*thinking*" Systems (e.g. Human Systems), at *any space-time scale* and in *variable conditions*. It was so renamed because the related concepts of Emergy and Transformity, introduced by H.T. Odum, are replaced by the concept of Ordinality.

On these bases, by adopting the M.O.P., every System can be described as a "Self-Organizing System".
At this stage, after having presented the main differences between the two afore-mentioned *formal languages*, we can consider some ostensive examples which can clearly show their profound (both conceptual and practical) differences.

3. Ostensive examples in various different fields of analysis

As anticipated in the Abstract, we will now consider some ostensive examples (among many other possible).
In particular: *i) the research for equilibrium conditions in a free-market economy; ii) the development of renewable energy sources; iii) climate change forecasts, iv) and some problems related to human health (such as, for instance, new oncological therapies).*

3.1 The research for equilibrium conditions in a free-market economy

Neo-Classical Economics, which at present seems to represent the most followed Economic Theory in the world, usually adopts the Traditional Differential Calculus (TDC) as its proper formal language.

In spite of its wide theoretical diffusion, Neo-Classical Economics is characterized, from its same origin (at the beginning of the XX century) by an unsolvable problem: *The three-good two factor Problem*, which has never been solved up to now.

This Problem (as clearly states its "title") consists in the fact that, given three goods, in a free market, characterized by two productive factors (*Kapital* and *Labour*), such three goods do not reach an equilibrium condition.

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[1] These "*new mental categories*" can no longer be termed as "pre-suppositions", because they are not defined "*a priori*" (as in the case of the Traditional Approach). In fact, they are chosen only "*a posteriori*", on the basis of the "Emerging Quality" *previously recognized* from a phenomenological point of view. "*Generative Causality*", in fact, refers to the *capacity* of a Self-Organizing System to manifest an "irreducible excess"; "*Adherent Logic*", correspondently, refers to the capacity of our mind to draw "*emerging conclusions*". That is, "conclusions" whose information content is much higher than the information content corresponding to their logical premises, although persistently "adherent" to the latter. "*Ordinal Relationships*", in turn, refer to *particular* relationships of *genetic nature* (similar to those between two brothers), which will be illustrated in more details later on in the various examples considered in the paper.

This result clearly shows that a free market cannot be considered as being a simple "mechanism".
A free market, in fact, is characterized by "Initiative", "Inventiveness" (understood as a "continuous development of new products"), without considering that *any transaction* always generates "*Extra*" *Benefits of Ordinal Nature* (Giannantoni, 2009), which are *irreducible* to a traditional description in terms of *causality*, *necessity*, *functionality*.

All these conditions suggest that a free market can more appropriately be model as a "Self-Organizing System". This is because the above-mentioned characteristics always represent "Emerging Aspects" which cannot properly be represented in terms of TDC.

In fact, when "*The three-good two factor Problem*" is modeled as a "Self-Organizing System" in the light of the M.O.P. (that is in terms of IDC), the Problem can be solved for an *arbitrary number of goods* (N_g), in the presence of *Three Productive Factors: Capital (K), Labour (L) and Natural Resources (N)* (Giannantoni, 2011).

The corresponding "Emerging Solution" is given by the following Harmony Relationships (ib.)

$$\{\tilde{K}_{1,j+1}, \tilde{L}_{1,j+1}, \tilde{N}_{1,j+1}\} \overset{*}{=} (\sqrt[N-1]{\{\tilde{1}\}})_j \circledR \{\tilde{K}_{12}, \tilde{L}_{12}, \tilde{N}_{12}\} \qquad j = 1,3,......N_g - 1 \qquad (3),$$

where, as usual, the index "12" represents an *arbitrary* couple of goods assumed as a reference, while the term $(\sqrt[N-1]{\{\tilde{1}\}})_j$ represents the $N_g - 1$ Ordinal Roots of Ordinal Unity $\{\tilde{1}\}$ (Giannantoni, 2012).
It is also obvious that, in the presence of two sole productive factors, the solution can simply be obtained by assuming that $N = 0$.

3.2 Development of renewable energy sources. Intrinsic Instability of Smart Grids

This example could also be seen as a transposition, to the case of Smart Grids, of the same concepts previously analyzed in economic terms.

A Smart Grid, in fact, is designed on the basis of electromagnetic laws that are valid for electrical circuits (Kirchhoff's laws). This means that any Smart Grid is conceived as a sort of a "mechanism", formally described in terms of Traditional Differential Calculus (TDC).

Now, the same fact that a Smart Grid may present some form of "instability" suggests that its conception as a "mechanism" is not the most appropriate one.

From a phenomenological point of view, in fact, when a Smart Grid reaches the number of about 100.000 plants (or more), it may present some forms of instability. The latter can always be described, in pure formal terms, as being associated to a distortion "drift" in some physical parameters (with respect to a perfect sinusoidal trend). Such a "drift" generally tends to amplify even under normal exercise conditions, because of the different currents produced by the *N* generators (Giannantoni, 2012).

However, when the instability leads to a blackout, the latter can more properly be considered as a form of "*side effect*" of the Smart Grid. In fact it can precisely be seen as the consequence of the fact that the Grid is conceived in such a way as all the electrons are "forced" into the Grid according to Kirchhoff's laws, by means of N generators, which, on the other hand, are *topologically* distributed according to some particular and specific "*functional*" exigencies.

Such a particular behavior, on the contrary, can more appropriately be seen as the manifestation of some "Emerging Properties" (of a Smart Grid) which cannot be "captured", in formal terms, by means the "rigid properties" of the Traditional Differential Calculus (TDC).

This becomes particularly clear if we consider what was already pointed out by P. Anderson (Nobel Prize *in Physics* 1977): "*A complex aggregate of electrons shows properties that are not reducible to their sum*" (Anderson, 1972). In other words, "*a complex aggregate of electrons*", although "forced" by generators into electrical circuits, always tends to behave as a "*Self-Organizing System*".

This means that, by modelling a Smart Grid in the light of the M.O.P., and thus in terms of IDC, the distribution of the *N* Generators (and their related connections) should not be designed in *mere functional* terms. On the contrary, they should *topologically* be distributed in such way as the Voltage ($\tilde{V}_i$), Current ($\tilde{I}_i$) and Phase ($\tilde{\Phi}_i$) of each generator satisfy, at any time *t*, the Harmony Relationships pertaining to the Smart Grid under consideration:

$$\{\tilde{V}_{1,j+1}, \tilde{I}_{1,j+1}, \tilde{\Phi}_{1,j+1}\}_t \overset{*}{=} (\sqrt[N-1]{\{\tilde{1}\}})_j \circledR \{\tilde{V}_{12}, \tilde{Y}_{12}, \tilde{\Phi}_{12}\}_t \qquad j = 1,3,......N - 1 \qquad (4)$$

where, as usual, the index "12" refers to an *arbitrary* couple of generators assumed as reference, while $(\sqrt[N-1]{\tilde{1}})$ represents the N-1 Ordinal Roots of Ordinal Unity ($\tilde{1}$) (Giannantoni, 2012).

Under such conditions, the Smart Grid not only presents an *intrinsic Ordinal Stability*, but also presents, as an "Emerging Exit" (or "Extra Benefit"), an *additional* Ordinal Stability with respect to *cyber attacks* too. (ib.).

3.3 Climate change forecasts. The "Unexplained" Sea Level Rise over the Period 1900-2000

Global sea level has been rising at a rate of around 1.8 mm per year (i.e. 18 cm/century). This rate is still increasing. Measurements from satellite altimetry indicated a mean rate of 3.1 mm/year in the period 1993-2003 (IPCC, 2007). More recent data indicate a value of 3.2 mm/year (WMO, 2013).

The real trend of such an increase has been registered by means of 23 long tide gauge records, in geologically stable environments distributed all over the world, provided by the Permanent Service for Mean Sea Level (2010). Theoretical estimations, on the contrary, lead us to foresee a trend of 6.0 cm/century.

Such a discrepancy represents an "enigma". In fact: "Two processes are involved: an increase of the mass of water in the oceans (the eustatic component), largely derived from the melting of ice on land, and an increase of the volume of the ocean without change in mass (the steric component), largely caused by the thermal expansion of ocean water." (Meier & Wahr, 2002, p. 1).

The eustatic contribution of 6 cm attributed to IPCC leads to a *residual rise* to be explained of 12 cm to the end of the century, which cannot be accounted for by steric expansion only. (ib.)

On the other hand, other potential effects do not seem to be able to explain such a difference. This is because, *from a simple quantitative point of view*, they only give marginal contributions. Consequently, they are insufficient to account for the observed drift of 12 cm.

A preliminary interpretation of such a "drift", essentially based on the differences between the expansion series expressed in terms of TDC and, correspondently, the expansion series obtainable by adopting IDC, has already been given in (Giannantoni & Zoli, 2009). In that case the resulting analysis led us to show that the description of the process in terms of "Incipient Derivatives" is able to explain a net increase of *not less than* 17.0 cm/century (ib.).

This result is already sufficient, by itself, to show that the "un-explained" recent sea level rise is due more to an intrinsic limitation of the mathematical models usually adopted to describe physical systems (in terms of TDC) than to new (or not yet identified) causes. This can surely be asserted precisely because the obtained results do not refer to *future* trends, but concern *past* effects, that is already registered and accurately measured.

The afore-mentioned results, however, can also be analyzed from a more general point of view. That is, in the light of the M.O.P.. In particular, by means of an associated Ordinal Simulator termed as "Emerging Quality Simulator" (EQS), which faithfully represents the various Harmony Relationships between the *different parts* of the system analyzed.

The Simulator, in fact, is structured in such a way as to represent the *Ordinal Interactions* between *all* the *different* physical Systems involved in the process (sea, ice, hearth, sun, etc.). Interactions that, because of their Ordinal Nature, are precisely those that represent the real "*generative cause*" of that registered "unexpected" trend.

According to such an interpretation, in fact, it becomes evident that the *"unexpected" trend* of the sea level rise is nothing but an "*Emerging Exit*" of *a unique* "*Self-Organizing System*".

Such an example is particularly meaningful because it clearly shows that the "*separation*" between different effects (as usually happens when adopting an approach based on TDC) not always leads to the expected results.

3.4 New Oncological Therapies. The Immuno-targeted Therapies

The Immuno-targeted Therapies (or molecularly targeted therapies) represent one of the major modalities of medical treatment for cancer. Such therapies, in fact, block the growth of cancer cells by interfering with specific targeted molecules needed for carcinogenesis and tumor growth.

Targeted cancer therapies are very promising, because they are expected to be more effective than older forms of treatments and less harmful to normal cells.

The most successful targeted therapies are substantially based on *chemical entities* that target a protein (or enzyme) that carries a mutation or other genetic alteration that is specific to cancer cells.

However, a fundamental "*limitation*" of targeted therapies is represented by the fact that, at present, it is impossible to know *in advance* the *affinity* between the selected "molecule" and its corresponding "target", because of the intrinsic insolvability, in *explicit terms*, of the famous "Three-body Problem", as demonstrated by H. Poincaré in 1889 (Poincaré, 1952). This also leads to a corresponding *additional* "*limitation*": the *intractability* of the problem in numerical terms. In fact, the research for a numerical solution to the afore-mentioned interaction problem often overcomes the computation capacities of the most powerful computers at present available (10 Petaflops).

Both such *limitations*, however, are simply a direct consequence of the fact that, *in essence*, any targeted therapy is always conceived as a "mechanism". In fact, any targeted therapy is understood as an interaction between *two basic entities*, both thought (and modeled) as two distinct "mechanisms" that, through their reciprocal interaction, give origin to an even more complex final "mechanism".

As it is evident, such a particular description is nothing but a *necessary* consequence of the mathematical language adopted (namely TDC) and its "subjacent" presuppositions (see Tab.1).

As a further direct consequence of such a description, the *efficacy* of any targeted therapy can only be defined "a posteriori". That is, only on the basis of the results of corresponding *ex post* analyses, based on *in vitro* and *in vivo* tests, and only after some preliminary specific tests (of the same therapy) on a restrict number of selected patients.

If, on the contrary, the considered targeted therapy is modeled as an interaction between two Self-Organizing Systems, it is always possible (as already shown in *the more general case* of Protein-Protein Interaction (Giannantoni, 2015)), to get the *explicit formal solution* to the process and, consequently, the corresponding formal structure of the final compound, together with its *associated topological configuration*. The latter, in fact, when compared with the topological configurations of the two interacting systems, enables us to evaluate, *in advance*, the *affinity* between the two interacting entities and, correspondently, to foresee the *real efficacy* of the therapy.

As it is easy to understand, this different approach to a pharmacological evaluation of targeted therapies offers some very important advantages. In fact:

i) in the case of two or more *theoretical* "entities", all of them designed for *the same* targeted therapy, the approach based on Self-Organizing Systems (and thus on the *formal language* IDC) allows us to establish a "hierarchy" between the various pre-designed "molecules" under consideration. A "hierarchy" which is based, in particular, on their specific *affinity* with the selected target and, consequently, on the potential *efficacy* of the corresponding targeted therapy.

What's more, the basic advantage is that such a "hierarchy" can evidently be obtained *a priori*. This allows us to focus on the most efficient "molecule" (among all those theoretically designed for the same targeted therapy), and then to research for the corresponding experimental confirmation through appropriate tests (*in vitro*, *in vivo*, etc.) with *exclusive reference* to the most favorable "molecule" selected on the basis of the previous formal approach. This leads to save both costs and time, because it becomes possible to neglect all the other *less favorable* potential possibilities;

ii) a further particular advantage manifests when the targeted therapy foresees the adoption of two (or more) molecules, theoretically designed so as to interact with the same selected target according to a pre-defined *time sequence*.

In such a case the approach based on IDC is able to show that the most appropriate sequence of the two (or more) considered entities can lead to a "*global efficacy*" which can be even higher than the corresponding efficacy when the latter is estimated by considering two distinct and separated interactive processes. This is because, as it usually happens in Self-Organizing Systems, "*The Whole is much more than the sum of its parts*".

4. Two "*com-possible*" formal languages, albeit "not equivalent" between them

The two formal languages, TDC and IDC, respectively, when considered with reference to their corresponding "presuppositions" (that is the subjacent "way of thinking") result as being two different formal descriptive modalities which are always "*com-possible*". In the sense that they *do not exclude each other*. They simply *co-exist*.

This is because, as already anticipated, the Traditional Scientific Approach, which leads to TDC, *cannot exclude* (in principle) the adoption of a different formal language (e.g. IDC), because of the *absence* in its presuppositions (especially "necessary" logic) of any form of *perfect induction*. On the other hand, the same happens in the case of the adoption of IDC, precisely because of the *same reason*, although the latter is based on presuppositions characterized by a different form of logic (e.g. the "adherent" logic).

Consequently, the two formal languages, TDC and IDC, can *always* be adopted independently from one another. Although this "com-possibility" does not mean that they are "equi-valent" between them.

Their "in-equivalence", in fact, can easily be shown by comparing the different *consequences* of their respective adoption, when such consequences are obviously considered in the light of their corresponding "presuppositions".

In fact, *beside* the Traditional Scientific Approach, which affirms that "Every System is a *mechanism*" (at a phenomenological level), there is also the possibility of a different Approach, according to which "*Every System is a Self-Organizing System*" (always at a phenomenological level). This is the fundamental reason why they lead to the adoption of *two corresponding different formal languages*, with some associated important consequences.

In the first case, in fact, the adoption of TDC leads to:

i) *Unsolvable Problems* (in explicit formal terms);

ii) *Intractable Problems* (even by adopting the most advanced computers);

iii) *Problems characterized by experimental "drifts*", which always represent an indication of possible "side effects";

iv) In addition, it is worth pointing out that TDC can lead to some "side effects" even in the case of accurate experimental confirmations. Such "side effects", in fact, can result as being "masked" by the same fact that all the experimental confirmations are always based on the adoption of *methods, instrumentation and measurements* that are conceived (and designed) in a perfect conformity with the fundamental presuppositions of TDC (Giannantoni, 2016).

Vice versa, the adoption of IDC does not present such problems, whereas, in turn, it presents several advantages. In fact, as already anticipated, the adoption of IDC is finalized to describe the "Emerging Quality" of "Self-Organizing Systems". This leads to the formulation of the M.O.P., which is able to offer *a radically New Perspective* to Modern Science. That is: "*Every System is a Self-Organizing System*" (see Tab. 1).

This is because IDC is the most appropriate language able to describe the fundamental characteristics of "Self-Organizing Systems". In fact, the "Incipient Differential Calculus" (IDC):

i) is able to represent, in appropriate formal terms, the "Emerging Quality" of Self-Organizing Systems as an "*Irreducible Excess*";

ii) In this way TDC enables us to formulate a very general Principle, the Maximum Ordinality Principle (M.O.P.), which can be understood as "*One Sole Reference*" Principle (Giannantoni, 2014);

iii) The latter in fact results as being valid *in any field* of analysis (from *non-living* Systems, to *living* Systems and *human social* Systems too);

iv) In addition, the adoption of IDC *always* leads to *explicit formal solutions*;

v) At *any topological scale* (e.g. from atoms to galaxies);

vi) Both *under steady state and variable conditions*;

vii) What's more, the corresponding Solution to *any* mathematical model based on the M.O.P. (and thus formulated in terms of IDC) always results as being an "Emerging Solution". That is, a Solution whose *Ordinal Information content* is always much higher than the Ordinal content corresponding to the initial formulation of the problem;
viii) As a direct consequence, this leads to the fact that any "Emerging Solution" can never be reduced to mere "functional relationships";
xi) This is also means that the adoption of IDC *does not require any* specific reference to the traditional Physical Laws or to the well-known Thermodynamic Principles (precisely because the latter are always understood as "functional relationships");
xv) Finally, the adoption of TDC never leads to "side effects". This is because, even when an "Emerging Solution" might manifest some related "Emerging Exits" (Giannantoni, 2016), the latter can always be interpreted as being corresponding "Extra Benefits", initially not recognized as such.

4.1 More general *in-equivalence* between TDC and IDC, especially with reference to the relationships between Man and the Environment

Although from a general point of view the *in-equivalence* between the two formal languages can preliminarily be recognized at the level of "Thinking", such an in-equivalence is even much more marked at the level of "Decision Making and Acting". Especially when considering, as a basic reference criterion, the corresponding different concepts of "inter-relationships" between Man and the Environment (Giannantoni, 2016).

This is because the adoption of TDC always "reflects" the general idea that "every system is a *mechanism*", while the "com-possible" formal language IDC is always orientated at describing any system as a "*Self-Organizing System*". This is the fundamental reason for the adoption of the three *new mental categories* shown in Tab. 1, which are radically different from the three basic presuppositions of the former.

This easily leads to recognize that the most profound "in-equivalence" between TDC and IDC situates at the level of Decision Making and Acting. In fact:
i) At the level of "Decision Making" the two formal languages will evidently lead to make decisions (that will become consequential future *actions*) in a perfect *conformity* with their respectively different way of thinking: TDC, in conformity with its "*aprioristic*" presuppositions; IDC, vice versa, in conformity with the *new mental categories* that, on the contrary, are adopted "*a posteriori*".

Consequently, in both cases the two formal languages will suggest "decisions" in perfect *conformity* with their corresponding concepts of "*surrounding habitat*": understood as a "*set of mechanisms*", in the case of TDC or, respectively, as "*a unique Self-Organizing System*" in the case of IDC (Giannantoni, 2016);
ii) At the level of Action, however, it is exactly *where* it is possible to recognize the most marked differences between the two formal languages. This is because, in such a case, the specific different *origin* of each formal language, together with the associated *powerful expressive capacity that any formal language is able to manifest*, represent the fundamental aspects that systematically "guide" (sometimes even "force") the research for specific practical solutions to the various problems and their subsequent actual implementation.

In other terms, the profound differences between TDC and IDC become particularly evident at the "level of Action", because the corresponding formal solutions *become* consequential *facts* (Giannantoni & Zoli, 2010).
In this respect, the Ostensive Examples previously considered should be sufficiently clear to show the profound differences that may result, *in practice*, when adopting the one or the other descriptive formal language.

Consequently, especially because of the fact that the profound "*in-equivalence*" between the two formal languages clearly manifests at the level of "facts", this may suggest, as a possible conclusion, the consideration of an extremely important question: "where are we going" as a consequence of the adoption of one (or the other) descriptive formal language": TDC or IDC?

5. Conclusion. Where are we going?

The afore-mentioned differences between the two considered formal languages, TDC and IDC, which can preliminarily be recognized at a gnoseological level but, even more, at the level of their respective *practical* consequences (such as those shown in the examples previously analyzed), enable us to draw some general conclusions which can be synthetically summarized as follows.

From a general point of view, in fact, it is possible to delineate three possible answers:
i) Modern Science is so radically rooted in TDC (and in its corresponding presuppositions) that it is extremely improbable to hypothesize, in spite of the afore-mentioned intrinsic *limitations* of such a formal language, a rapid change of the corresponding paradigm. In this sense we have to expect a generalized persistence in the adoption of the traditional formal approach (TDC);
ii) this fact, however, does not prevent from thinking that, occasionally, and with reference to specific problems, some Scientists will decide to *exclusively* adopt the innovative IDC approach;
iii) more probably, because of the afore-mentioned "*com-possibility*" between TDC and IDC, it may be expected the adoption of both formal approaches *at the same time*, so as to choose the optimal *operative* solutions on the basis of the corresponding experimental results. By always taking into account, however, that TDC translates, in formal terms, a "*self-referential*" gnoseological approach, while IDC represents, always in formal terms, a "*hetero-referential*" gnoseological approach (as clearly illustrated in the paper and synthetically summarized in Note 1).

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www.ordinality.org: author's website that presents a general framework about the M.O.P, from the Mathematical Formulation of the Maximum Em-Power Principle up to the Mathematical Formulation of the M.O.P., together with some Ostensive Examples mentioned in this paper.

LCA-based Emergy Analysis on the Whole Chain of Aluminum in China

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Abstract

As China accounts for over 50% of global primary aluminum production now, no country's policies interest the aluminum world more. The aluminum industry has taken a life-cycle approach to manufacturing and designing its products, which can be observed in the aspects of policy making and technology application. Life cycle assessment (LCA) approach emphasizes responsibilities in managing products, services, and/or business operations throughout the entire life of the product—from product to recycling to new product. In the case of aluminum, this involves the management of resources, minimizing energy consumption, emissions and waste releases to the environment, while keeping a focus on the overall economic, social and environmental benefits that the products bring to society. LCA-based Emergy methods, which is a measure that accumulates all the energy used up in the process of creating any item in terms of a common energy unit, include the inputs such as labor, service and the work of the environment and assuming equivalent conditions. In other words, LCA-based Emergy analysis is used to identify the balance between the socioeconomic development and natural environment and try to fit the concerned production procedure into the multidimensional surrounding ecosystems. In this study, a Life Cycle Inventory (LCI) based on Emergy Analysis was assembled and four processes were decomposed, including deposit formation; production processes (such as bauxite mining, alumina refining, electrolysis and ingot casting, aluminum products manufacturing and fabrication); using process; the aluminum recycling and regeneration process. This study updates the UEV (unit emergy value) of different aluminum outputs in the five processes.

1. Introduction

Recycling is significantly helpful for resource conservation and energy reduction. Aluminum is one of the most recyclable of all materials on the market today and its manufacture is one of the most energy intensive. To reduce the energy and resource consumption, long-term strategic targets for aluminum production have been established (Lin and Xu, 2015). Moreover, China plays a more and more essential role in the global aluminum production. Since the year 2000, there has been a significant increase of the production of primary aluminum in China, with its contribution to the global production climbing from 15% in 2001 to 49.4% in 2014 (Ding et al., 2016). The aluminum product process is a long chain. LCA approach is widely applied nowadays for its ability of enabling precise positioning according to production stages. LCA-based Emergy method is a comprehensive method which can quantify the environmental contribution and impacts of systems or products

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throughout the whole life cycle from the exploration of the raw materials and fuels, to the final disposal or recycling, which is also called from cradle to grave (Pehnt, 2006). Brown (2016) evaluated the aluminum production chain and using emergy analysis computed unit emergy values (UEVs) at each production step, using published life cycle inventory data for a single USA manufacturer.

Emergy analysis is a valuable approach which can emphasize the performance and sustainability of a system by analyzing the sum of all direct or indirect inputs of available energy required by a process to provide a given product or flow, utilizing the same form of energy called solar emergy (sej) (Odum, 1996). The UEV is the emergy required to generate one unit of output (product) expressed as sej/J (transformity), or sej/g (specific emergy), or sej/$ (emergy money ratio). When comparing products of the same composition and use, such as aluminum product, the use of UEV helps to formulate policy regarding best use of resources. Those products of the same class that have lower UEVs require lower quantities of resource embodiment.

Brown's (2016) UEV for aluminum has been used generically in other situations including evaluations in China. Undoubtedly, the need for a UEV of aluminum in China would provide needed precision for future China specific emergy evaluations and more accurate policy making related to the Chinese aluminum system. In this paper, the UEVs of Chinese different aluminum outputs in each stage were updated. What's more, a comparison between UEVs of aluminum production outputs in China and the USA was employed to analyze the situation of Chinese energy and resource consumption.

2. Methodology

2.1 Emergy flow diagram of Chinese aluminum industry

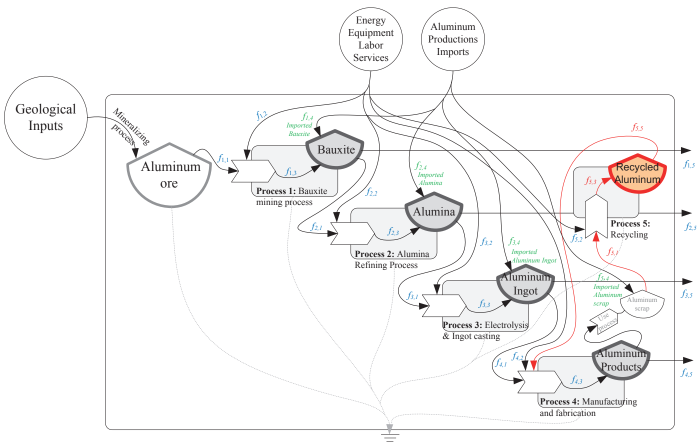

Figure2.1: The energy-flow diagram of China's aluminum production system in 2005, showing the main stages of production: bauxite mining (1), alumina refining (2), electrolysis and ingot casting

(3), aluminum products manufacturing and fabrication (4), and recycle (5). The diagram also shows imports and exports of various aluminum products.

Figure 2.1 is an energy systems diagram of the Chinese aluminum production system. The spatial boundary of the study is the geographical border of mainland China, and the temporal boundary is the year 2005. The long aluminum production chain highlighted by Liu and Mueller (2012) was used in this study. The chain, shown in Figure 2.1, includes deposit formation and production processes (such as bauxite mining (1), alumina refining (2), electrolysis and ingot casting (3), aluminum products manufacturing and fabrication (4)), as well as the aluminum recycling and regeneration process (5) after use.

2.2 Data sources

The data of aluminum in each stage was completed in accordance with the research of Chen et al (2008). Data sources are various including governmental or industrial statistics (CSY, 2006); some academic papers such as Ding et al. (2016) and Brown and Buranakarn (2003); books and research reports, such as the forth sustainable bauxite mining report; and other information. Most transformities used in this article are from Brown et al. (2016). But the transformity of dollars is from Lou and Ulgiati (2013).

It should be mentioned that the emergy baseline used in this study was 12.0 E24 sej/yr.

2.3 Characteristics of China's bauxite

The bauxite in China has a characteristic of high alumina and silica content. Table 2.1 describes that more than 60% of mineral composition of Chinese bauxite is diaspore and there is almost no gibbsite content which is less than 3%. Compared with high boehmite and gibbsite content abroad, these shortages of bauxite resources in China lead to the difficulties in mining. More bauxite ore is needed for the unit quality production in China than in other countries due to the Chinese bauxite composition. Compared with a stripping ratio of 1.3kg/1kg in the US, China needs 5.85kg bauxite ore to produce 1kg bauxite.

Table 2.1 Typical Chemical and Mineral Compositions of Chinese Diasporic Bauxite (From Don, D. and Benny E. R., 2013)

Items	Composition	Bauxite Location		
		Guangxi	Henan	Shanxi
Average mineral composition%	Diaspore	60.25	69.52	65.71
	Gibbsite	2.18	/	/
	Kaolinite	4.99	2.77	25.85

	Illite	1.04	7.11	2.01
	Hematite	5.48	2.45	1.0
	Goethite	15.41	/	/
	Anatase	2.69	1.6	2.9
	Rutile	0.48	0.59	0.52

The ratio of alumina to silica in weight percentage (A/S) has a great influence on the consumption of energy and other processing inputs in the alumina refining process. As shown in Table 2.2, it illustrates that about 68% of the Chinese bauxite belonging to the low or middle grade, whose A/S ratio is less than 7. Because of the lower grade of bauxite, traditional Bayer process isn't appropriate in Chinese alumina production industry which may cause a significant loss of alumina. Consequently, the Bayer- sintering process is developed. Even though the loss of alumina is being avoided, high energy is also consumed. It is indicated in this research that the most two input contributions to the alumina refining process are the coke and coal. At the same time, the energy consumption is as high as 29,348MJ/per ton of alumina in Chinese alumina production, which is more than twice of the world[2].

Table 2.2 Grade Distribution and proportion of Chinese Bauxite (From Don, D. and Benny E. R., 2013)

A/S	<4	4-6	6-7	7-9	9-10	>10
Reserve proportion range,%	7-8	48-49	10-11	14-15	11-12	6-7

It is important to mention that Chinese government has pushed the primary aluminum industry to upgrade their prebake cell facilities beginning in the year 2000. Data provided by the International Aluminum Institute shows that the energy consumption per ton of aluminum in China is 14,574 Kwh which is lower than the average primary aluminum smelting energy intensity of the world [3].

3. Results

Table 3.1 Comparison between UEVs of aluminum production outputs in China and the USA (sej/kg)

	Mined Bauxite	Alumina	Aluminum Ingot	Recycled Aluminum	Aluminum Products
China	1.92E+11	5.05E+12	3.73E+13	3.38E+13	4.69E+13
China (wol&S)[a]	1.56E+11	4.90E+12	3.71E+13	3.37E+13	4.66E+13
USA (Brown &	3.38E+10	1.63E+12	3.36E+13	2.9E+13 [b]	4.7E+13[c]

[2] http://www.world-aluminium.org/statistics/metallurgical-,alumina-refining-energy-intensity/#data
[3] http://www.world-aluminium.org/statistics/metallurgical-alumina-refining-energy-intensity/#data

Ulgiati, 2018)					

a . Without labor and services
b. Based on aluminum can only (Brown, 2016)
c. Based on Aluminum sheet only

Table 3.1 shows the UEVs for each stage of Chinese aluminum production in 2005 calculated in this study compared to UEVs for aluminum products in the USA computed by Brown and Ulgiati (2018). China's UEVs for bauxite, alumina and aluminum ingots are all higher than corresponding USA products, due primarily to the higher energy consumption in the mining, refining, and smelting stages. As mentioned above, the quality of Chinese bauxite is lower than that found in western countries and therefore its UEV reflects this fact, being almost 5 times higher than the USA bauxite UEV. Also with the higher energy requirements of the mining phase, the UEV of alumina is about 3 times that of the UEV for USA alumina.

However, due to recent efficiencies mandated by government, the UEV for aluminum ingot is only about 11% higher.

The total emergy per kilogram of the recycled aluminum (Table 3.1) is lower than that of aluminum ingot due to the fact that re-melting of recycled aluminum scrap requires less energy than alumina as a result of the use of electricity in the production of aluminum ingots, while the re-melting of scrap uses the heat from coal burning. The UEV of recycled aluminum in China is somewhat higher than that of the USA, primarily because the USA value is for aluminum can only while the China UEV is for mixed scrap that contains other sources than just cans. The final products in China and the USA have very similar UEVs even though China's UEVs in earlier stages are higher. This primarily due to the low UEVs of imports, which decrease overall the emergy at each stage.

4. Conclusion

In this study, an LCA-based emergy method was applied for the aluminum industry in China to update the UEVs of aluminum outputs in each stage. Furthermore, a comparison between UEVs of aluminum production outputs in China and the USA was employed to formulate Chinese policy regarding best use of resources. The higher UEV shows the situation of Chinese lower grade bauxite, and the higher energy consumption in the mining, refining, and smelting stages due primarily to China's energy structure.

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Influencing Household Energy Consumption: The Active House in Stockholm Royal Seaport

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Abstract

Smart grids are expected to play a key role in realizing future power systems of increased reliability, efficiency, and competitiveness. As an essential demand side management strategy, residential demand response aims to influence household energy consumption for increased energy efficiency and demand flexibility, bringing the potential benefits of smart grids to fruition. Although previous research suggests that demand response intervention strategies based on real-time feedback and smart home energy management systems have a clear potential to stimulate to changes in energy consumption behavior, the literature also addresses the need to further explore the potential of residential demand response strategies by evaluation and analysis of practical implementation. In this paper a smart home intervention program focusing on demand response and consumer engagement is presented; the Active House in the Stockholm Royal Seaport. The program takes place in a new urban district in Stockholm and aims to stimulate to energy conservation and increased demand flexibility among 154 newly built smart homes equipped with a home energy management system, allowing households to monitor and control their energy use. The main contribution of the paper is to analyze and discuss the key components of the program, including; scope and involved actors, incentives for customer engagement, the features of the smart home energy management system, and the upcoming scope of evaluation of the program, focusing on potential scenarios, preliminary findings, and future work. Based on a conceptual evaluation framework developed within the scope of the program, it is suggested that the program has a clear potential to contribute to increased understanding on consumer engagement in demand response programs, providing key findings and outcomes for further research within the area.

1. Introduction

Smart grids are considered to play a key role in future power systems, realizing the ambitions of a reliable and competitive electricity grid that meets the emerging sustainability needs of increased energy efficiency, reduced greenhouse gas emissions, and increased integration of renewable sources (Amin and Wollenberg, 2005; Farhangi, 2010). However, the potential benefits of smart grids are heavily dependent on end-use customers willingness to adapt to demand response intervention strategies; reducing and adjusting their electricity consumption levels and patterns for increased energy efficiency and demand flexibility (Clastres, 2011; Darby and McKenna, 2012). Cities has been identified a key trial sites to investigate if such achievements are possible, providing the necessary resources of social, knowledge, and infrastructural capital (Hodson and Marvin, 2009; Belkeley et al., 2011).

In 2009, the City Council of Stockholm, Sweden, decided that a new city district; Stockholm Royal Seaport (SRS)–which is expected to be fully developed by 2030 and will then contain approximately 12 000 dwellings and 35 000 work spaces–will serve as a test arena and international model for innovative energy solutions and sustainable urban planning (City of Stockholm, 2009). To realize the ambition of a "sustainable district", an environmental and sustainability program was developed, establishing challenging objectives targeting increased energy efficiency (City of Stockholm, 2010). To contribute to the fulfillment of the objectives a research and development program focusing on smart grid technology and demand side management strategies was initiated; Smart Energy City (SEC). The SEC program consists of two subprograms; 1) Smart Grid Lab, focusing on improvements in the control and management of the electricity distribution grid, and 2) Active House, a smart home intervention program focusing on demand response and customer engagement.

The aim of this article is to discuss the Active House program and analyze its key components, including; 1) scope and involved actors, 2) applied incentives for customer engagement, 3) the features of the Active House home energy management system, and 4) evaluation approach including potential scenarios and preliminary findings. In the final section the contributions are concluded and further work is presented.

2. The Active House: Scope and Actors

The Active House (AH) is a residential demand response intervention program that aims to stimulate to energy conservation and increased demand flexibility with a set target of 5-15% peak load reduction among an experimental group of 154 newly built apartments in the SRS. The apartments, 72 rentals and 82 condominiums of varying size (1-5 rooms), are all heated with district heating and equipped with a home energy management system, allowing households to monitor and control their energy use. The tenants moved into their new apartments during the fall of 2016 and the program started the 1st of January 2017 and will run for at least one year.

Taking into account that the AH program aims to change the conventional regime for how the residential sector is integrated in the electricity grid, strong structures and organizations need to be involved in the process. Thus, besides the City of Stockholm who provides the area of the SRS and the Swedish Energy Agency who financially supporting the initiative, the AH program includes actors from a wide range of sectors; 1) Fortum, local utility company, and 2) Ellevio, local electricity distribution system operator, have both invested in new business models and market designs for the participating customers, 3) Ericsson has developed information and communication solutions, and 4) Electrolux has developed smart home appliances, to be integrated in the AH home energy management system respectively, 5) ABB has developed automation technology and monitoring systems, 6) NCC, HEBA and Erik Wallin are the builders of the apartments included by the program, and 7) the Royal Institute of Technology (KTH) is responsible for the assessment and evaluation process, conducting research on the program.

3. Incentives for Customer Engagement

Influencing household energy consumption has proven to be a challenging task, requiring end-use customers to change their everyday life and routines. According to a study of Karlsson and Widén (2008), where Swedish household electricity consumption patterns and activities are analyzed, household's electricity saving potential is related to four types of incentive categories; 1) informative, 2) administrative, 3) economical, and 4) physical. The AH program also introduce a fifth category to the scope; environmental incentives. Thus, the incentives included in the AH program are;

1) Informative Incentives

Feedback on energy consumption, including electricity, hot tap water, and heating are visualized on in-home displays, as shown in Fig. 3.1. The information is presented in real-time, hourly, daily, weekly, and monthly frequency and accompanied by historical and normative comparisons, allowing households to compare present consumption with prior own levels and/or with consumption by neighboring household of similar size and type. Real-time information is also given on indoor temperature and solar production from rooftop solar PV systems. Price information is provided in form of an hourly dynamic electricity price signal, showing the price of the next 24 hours, allowing the households to plan and schedule their consumption activities to periods of lower price.

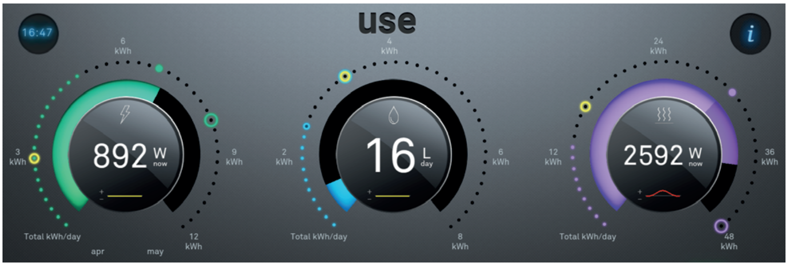

Figure 3.1: As visualized on the in-home display; real-time feedback on consumption of electricity (left), hot tap water (center), and heating (right), accompanied by historical (green ring) and normative (yellow ring) comparisons. By clicking on the icons monthly, weekly, and hourly feedback will be visible.

2) Administrative Incentives

The City of Stockholm's environmental and sustainability program for the SRS stipulates a set of objectives and requirements related to energy efficiency and measurements that the construction companies building in the area have to follow (City of Stockholm, 2010). For instance, the buildings should not exceed the energy performance target of 55 kWh/m^2/year and household individual measurement and debiting of electricity and hot tap water consumption is required. The construction companies participating in the AH program are all obligated to follow these directives, meaning that high-resolution measurement data are available for increased information and control.

3) Economical Incentives

An hourly dynamic electricity price tariff was introduced at the implementation of the program. The tariff is developed by the AH program with the aim to reduce consumption during peak demand periods, stimulating households to shift load from hours of higher price (peak hours) to hours of lower price (off-peak hours). In detail the tariff consists of two components; 1) hourly variable spot market price, and 2) a time-of-use tariff, varying from 1.05 SEK/kWh during peak hours to 0 SEK/kWh during off-peak hours. Peak hours are defined as the periods between 6 a.m. to 9 a.m. and 5 p.m. to 9 p.m. and off-peak hours are defined as the periods between 9 a.m. to 5 a.m. and 9 p.m. to 6 a.m., as shown in Fig. 3.2.

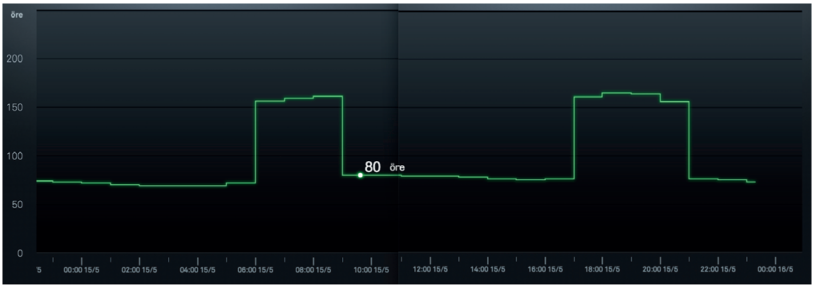

Figure 3.2: As visualized on the in-home display; electricity price forecast (öre/kWh) of the next 24 hours, showing the morning peak period (6-9 a.m.) and afternoon peak period (5-9 p.m.)

4) Physical Incentives

The participating households all have access to a home energy management system that builds on increased convenience and comfort of living (see Section 2.3). Through the system the households are able to control their indoor temperature, lightning, and appliances coupled to smart plugs. The system also includes a “home/away switch”, making it easy for the tenants to turn off all electricity devices when they leave their homes.

5) Environmental Incentives

The authors seek to explore the potential of using environmental incentives to stimulate changes in household energy consumption, comparing economic and environmental motivational factors. For that reason, the participating households in the AH program were randomly divided into two subgroups before the implementation of the program, equally distributed with respect to household characteristics (i.e. size, type of ownership, age, and household composition). Each household in the first group–the “economic incentive group”–are keeping their respectively cost savings obtained from individually changes in electricity consumption. In contrast, each household in the second group–“the environmental incentive group–are not keeping their respectively cost savings from individually changes in electricity consumption. Instead, the savings of these households are used by the program to purchase carbon emission rights, which are cancelled. However, all households, in both groups, are provided with the same price signal and receive feedback on their individually savings; the households in the “economic incentive group” in terms of cost savings and the households in the “environmental incentive group” in terms of reduced carbon emissions. This means that a half of the experimental households has an economic incentive to change their electricity consumption as a response to the price signal, while the other half has an environmental incentive to do change their electricity consumption.

4. Home Energy Management System

All households in the study are equipped with a home energy management system (HEMS), serving as an information and control center for the apartment. Through the HEMS displays and a mobile app the tenants are able to monitor their energy consumption, following the electricity price variations, and control all smart features, including lamps, lightning scenarios, and thermostat settings for different rooms, appliances coupled to smart plugs, and the home/away switch. The HEMS also include scheduling functions, supporting the households to reduce and shift loads, where washing machines and tumble dryers, as well as charging of electrical vehicles, may be scheduled to run when the price is at lowest within a defined time period of the next 24 hours, see Fig. 2.3.

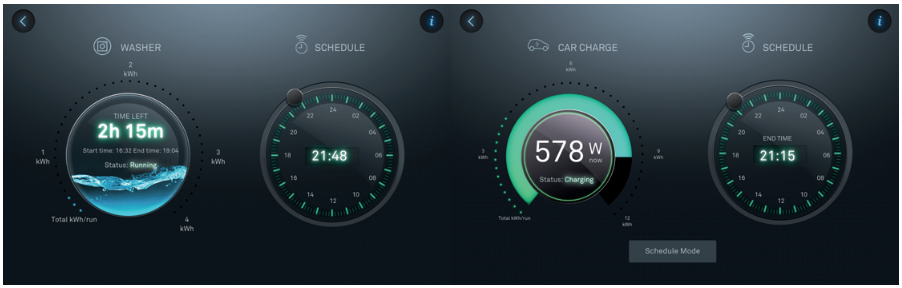

Figure 4.1: As visualized on the in-home display; scheduling of washing machine (left) and electric vehicle charging (right).

5. Project Evaluation: Potential Scenarios and Preliminary Findings

Within the scope of the research related to the AH program, a conceptual evaluation framework has been developed by the authors, attempting to provide increased understanding of the impact of feedback-based intervention strategies on household energy consumption. Building on a mixed methods approach, the framework aims to combine real-time user-generated meter data with data and findings from surveys and interviews for quantitative and qualitative analyses, deriving enhanced knowledge of energy consumption behavior and intervention effects of increased level of detail (Nilsson et al., 2017).

The program was implemented the 1st of January 2017 and thus still in its initial phase. As energy consumption behavior is strongly connected to long-term habits and routines, an analysis of potential behavioral changes must be based on data for a longer time period in order to be reliable and relevant. In the meantime, taking the project target of 5-15% reductions in peak load as a starting point, potential scenarios might be estimated. In Fig. 5.1 potential changes in demand curves as an effect of shifted consumption from peak hours to off-peak hours are illustrated. Peak load reduction is considered as a key achievement, leading to increased reliability and effectiveness of the grid, reduced emissions, and enables a higher share of renewable sources such as wind and solar in the power system. From the perspective of the customers, potential cost savings are completely dependent on individual measures and may vary widely. For the scenarios illustrated in Fig. 5.1 the annual savings in costs correspond to approximately 140 SEK, 270 SEK, and 400 SEK, respectively. However, it should be emphasized that potential benefits never can be taken for granted and that the potential of demand response interventions relies on several key factors, including households' perceptions and attitudes to provided feedback, the strengths of the scope of incentives, and the level of flexible loads in the homes (Nilsson et al., 2017).

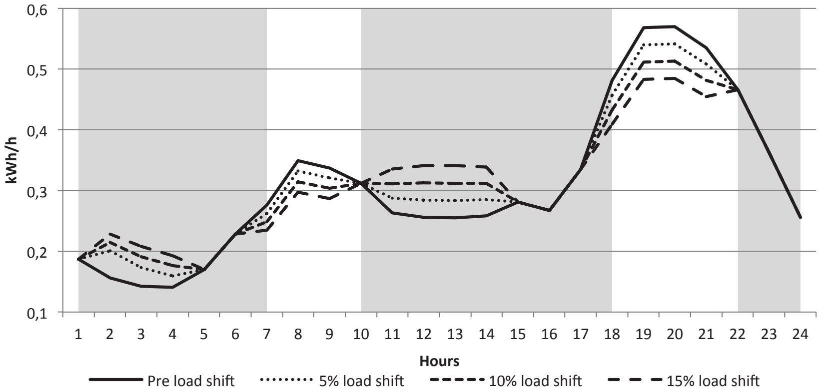

Figure 5.1: Potential load shift scenarios for a typical household in SRS, illustrating changes in intraday electricity consumption time patterns as an effect of 5%,10%, and 15% peak load reduction respectively (the light grey area represents the off-peak periods and the white represents the peak periods).

Besides collection of consumption meter data and quantitative analyses on energy consumption levels and patterns, the scope of the evaluation also includes collection and analysis of data retrieved from surveys and interviews with the involved households. A first round of surveys and interviews took place during the spring of 2017 and although a full analysis of the outcomes will be conducted during the fall of 2017, some preliminary findings on how the tenants have experienced the program so far are:

- There is a strong sustainability engagement among the households; the tenants want to contribute to a greener environment,
- The majority of the households perceive that their awareness and knowledge of their own energy consumption behavior has increased as an effect of the direct feedback and information,
- The HEMS has a great potential to be further developed based on input from the households, including; disaggregated feedback on appliances level, a more flexible and consumer-oriented interface, and possibility to take part of the information expressed in different units (kWh, SEK, gCO_2),
- The volatility of the dynamic electricity price tariff is too weak; the economic incentive to shift loads from peak hours to off-peak hours needs to be strengthened.

6. Discussion, Conclusions, and Future Work

By studying the case of the Active House program, the authors seek to explore the potential of influencing household energy consumption by demand response intervention strategies, aiming for reduced energy consumption and increased demand flexibility among 154 smart homes in the Stockholm Royal Seaport. To achieve the goal of changing the structures for how households are integrated in the power system a strong actor network is needed and the program involves a triple helix of public, academic, industrial sectors, including; utility companies, ICT and software developers, home appliances manufacturers, builders, and research institutes.

Further, motives to change household electricity consumption are not explicitly of economic character. Changes in everyday energy consumption activities and routines may also be retrieved by informative, administrative, and physical incentives. In addition, the authors seek to explore the potential of environmental incentives, investigating in the effects of letting half of the participating households in the AH program change their electricity consumption for environmental motives. To support the households to reduce and shift loads, all apartments are equipped with a home energy management system (HEMS), allowing the tenants to monitor, control, and schedule their energy use through their in-home display and/or mobile app. The HEMS is also developed with the aim to increase the comfort of living, including features to control the indoor temperature, smart plugs, and lightning. However, influencing household energy consumption is an extremely difficult task and there are no guarantees that the incentives provided in the AH program are strong enough for households' to change their consumption habits. For instance, the economic incentive of a dynamic electricity price tariff should be considered with regards to the high income-level of the district. It is reasonable to believe that residents in the SRS, living in expensive apartments centrally located in Stockholm are less affected by dynamic electricity prices compared to consumer segments of lower income levels. This considering is also supported by the preliminary findings from the surveys and interviews, where the households request a stronger economic incentive for shifting load from peak hours to off-peak hours.

Further work will focus on assessment and evaluation of the program, following the proposed conceptual evaluation framework. Based on statistical analysis of meter data the following quantitative parameters of analysis have been established:

- Impact on energy consumption levels; will the households reduce their overall consumption levels?
- Impact on electricity consumption time patterns; will the households respond to the dynamic pricing tariff by shifting load from peak hours to off-peak hours?
- Impact on maximum electricity demand; will the households reduce their consumption during critical peak periods?
- Impact on electricity demand curve shapes; will the households flattening out their demand curves as a response to the dynamic pricing tariff?
- Impact on consumer costs; will the households reduce their energy costs as an effect of changed consumption behavior?

The assessment of the parameters above will be evaluated with regards to findings from surveys and interviews, focusing on key aspects such as:

- Impact on awareness and knowledge; will the households increase their energy awareness?
- Impact on habits and daily routines; will the households change their energy-consuming activities as an effect of increased energy awareness?
- Perceptions and attitudes to the provided incentives; are the incentives strong enough for the households to change their consumption behavior?
- Experiences of the HEMS; are the smart features of the HEMS supportive enough for the households to change their energy consumption behavior?
- The potential of demand response intervention strategies related to socio-demographic characteristics; will households of different types (size, composition, income, age, etc.) respond to the incentives differently?

Hence, the evaluation of the program has a clear potential to contribute to increased understanding on consumer engagement in demand response intervention strategies, providing a comprehensive picture of potentials and challenges for further improvement and research within the area. However, the final analysis, fully revealing the results and findings of the project, is expected to be presented during the fall/winter of 2017.

7. Acknowledgement

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Strategic energy planning in different contexts: The modular approach to participatory backcasting

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Abstract

This study proposes a novel framework, modular participatory backcasting (mPB), for long-term planning in the heating sector. mPB is based on participatory backcasting and integrates principles of modularity, participatory modelling and transdisciplinarity. In mPB there are 13 modules, namely *Problem orientation, System boundaries, Current situation, Stakeholder analysis, Needs and functions, Vision, Criteria, Solutions, Drivers, Solution testing, Pathway, Action plan* and *Follow-ups*. The design of mPB and results of its implementation are presented for the cases of participatory strategic planning processes towards sustainable heat provision by 2050 in the Ukrainian city Bila Tserkva and the Serbian city Niš. The results show that mPB allows adaptability to a local context through exclusion, augmentation and substitution properties; decreases learning time for applying the framework in a novel context; increases reproducibility and transparency of long-term energy planning processes; enables efficient integration of quantitative methods into the participatory process; and advances collaboration between academia and society.

1. Introduction

Heating accounts for a considerable share of urban energy use in many countries (IEA, 2013). Sustainability transitions in the heating sector are crucial for dealing with sustainability challenges related to the emissions caused by heat generation from coal, natural gas and wood. An important approach in enabling such transitions is long-term energy planning, which could support a shift towards development and implementation of more sustainable solutions for heating. However, the current prevailing mode of planning in the heating sector is characterised by emphasis on system optimisation, consideration of a narrow space of alternative solutions and dominance of socio-economic criteria.

Backcasting, and later participatory backcasting (PB), has been suggested as a suitable approach to address long-term sustainability challenges in the energy field, since it can enable consideration of a broader space of possible solutions that are not based on existing trends and currently dominating technologies, meet environmental and social criteria and enhance participation by a broader range of stakeholders (Robinson, 1982; Dreborg, 2004; Quist, 2007). At the same time, the exploration of effects of various alternative technologies and their impact on climate, environment and social issues requires analytical methods and tools, including quantitative modelling that is rather well developed in the energy field (Herbst et al., 2012; Kirstead et al., 2012). Different analytical/quantitative methods have already been successfully integrated into PB projects (e.g. Zivkovic et al., 2016). However, wider integration of such methods into PB would require further study of emerging challenges, including those recently identified in the participatory modelling (PM) community, e.g. the need for methods to explicitly recognise human biases and heuristics during a PM process and approaches for resolving or compensating for these if needed; reducing the risk of 'group think' effects or dominance of one or a few individuals through a PM process; and dealing with the 'stakeholder fatigue' that can occur during a PM process (Voinov et al., 2016). Another set of relevant challenges has recently been identified in the transition studies literature when discussing emergence of computer modelling in the field. They include the influence of hidden assumptions, the risk of simplifications, challenges in uncertainty analysis, ambiguities in model interpretations and others (McDowall and Geels, 2017). Furthermore, more careful consideration of the skills and behaviour of modellers, along with a broader set of questions related to the ethics of modelling, must be addressed (Hamalainen, 2015).

Sustainability transitions in the heating sector are required in cities with various socio-political contexts. Therefore, adaptability of energy planning tools is very important for enabling their applicability under different conditions and limitations. Furthermore, projects related to the heating sector are often more 'local', in terms of relatively high level of the connection with a particular city, than e.g. electricity-related projects. This increases the probability that system boundaries for problem solving will be set according to geographical and administrative city boundaries, and not based on unbiased analysis.

This study suggests a framework for long-term planning in the heating sector that could support consistent and holistic analysis of a problem in a particular context, incorporation of sustainability criteria, and development and accurate analysis of different alternative solutions for heating through co-creation with the sector's stakeholders. It also allows adaptability and scalability to various socio-cultural contexts and project limitations (e.g. budget, time, skills available). The framework, modular participatory backcasting (mPB), is based on the PB approach (Quist et al., 2011), and incorporates principles of modularity (Baldwin and Clark, 2000), participatory modelling (Dreyer and Renn, 2011) and transdisciplinarity (Lang et al., 2012) (Table 1).

Table 1. Approaches and principles integrated in the design of modular participatory backcasting (mPB)

	Description	**Features**
Participatory Backcasting	Five-step approach: *Step 1*. Strategic problem orientation. *Step 2*. Development of future vision. *Step 3*. Backcasting analysis. *Step 4*. Elaboration of future alternative and definition of follow-up agenda. *Step 5*. Embedding results and agenda and stimulation of follow-ups.	Properties of normativity, long-term orientation, participatory/consensus-building
Modularity	Principle of decomposition into modules	Properties of exclusion, augmentation, substitution
Participatory modelling	Approach that links modelling with participation	Methods and techniques for integration of modelling into participatory processes
Trans-	Scientific principle aimed at concurrent	Joint problem definition;

disciplinarity	solving of a scientific and a societal problem by integrating and differentiating knowledge from various bodies of knowledge	principles and level of collaboration; furthering bottom-up initiatives

2. Participatory backcasting

Participatory backcasting as an approach to long-term planning includes development of a desirable future vision and further backcasting analysis to elaborate pathways and, if required, an action plan towards implementation of the vision. It is characterised by involvement of a broad range of stakeholders, long-term orientation, normativity and orientation on consensus building among stakeholders (Quist et al., 2011; Jansen, 2003). It is a flexible approach that allows for adaptability to a particular project purpose (see e.g. Vergragt and Quist (2011) for a review of PB projects), but this could also create a challenge of process reproducibility with achievement of similar results and outcomes.

Research in backcasting/participatory backcasting has been rather divided in terms of (i) advancement of the method and (ii) study of participatory processes and their effects. Nevertheless, research in each of these two sub-areas has resulted in a number of valuable findings. For example, assessment of the impact and consequences of different scenarios through multi-criteria analysis was described by Anderson et al. (2008); increased trustworthiness in PB through integration of the Delphi method was reported by Zimmermann et al. (2012); and a method for design of backcasting scenarios with a focus on resilience was suggested by Kishita et al. (2017). In these cases, backcasting was implemented in cooperation with experts and sometimes a broader range of stakeholders, but with a low intensity of stakeholder involvement. At the same time, other studies have reported a number of effects of PB processes with a high level of stakeholder involvement. For example, Doyle and Davies (2013) concluded that PB processes have a positive influence on stakeholder learning; Carlsson-Kanyama et al. (2008) discussed the influence of PB process design on the quality of the results; Sisto et al. (2015) reported a positive effect of PB processes on democratisation of policymaking; Eames and Egmose (2011) described the contribution of a PB process to formation of a local transition arena; and Neuvonen and Ache (2016) demonstrated potential of PB processes to bring about strategic learning among stakeholders. The authors have already obtained encouraging results regarding advancing PB as a unifying framework that integrates the benefits of analytical/quantitative methods and delivers effects of participatory processes (see Pereverza et al., 2017; Zivkovic et al., 2016). Further research in this direction seems promising.

3. Modularity

To address the need for adaptability and scalability to specific conditions and limitations, this study applied the concept of modularity to a framework design. Modularity in this context is the decomposition of a framework into modules characterised by "*the interdependence of decisions within modules; the independence of decisions between modules; and the hierarchical dependence of modules on components embodying standards and design rules*" (Baldwin et al., 2014). Modularity could enable the following reconfigurations of the framework:

- *Exclusion*[*] – possibility to select subsets of modules, excluding those not required for a project purpose
- *Augmentation*[*] – possibility to add a module to give some new type of functionality
- *Substitution*[*] – possibility to upgrade existing modules.

4. Participatory modelling

Participatory modelling can be broadly defined as an approach that involves linking modelling with participation (Dreyer and Renn, 2011). PM studies can provide a number of relevant insights for design of a framework which integrates quantitative analytical methods and a participatory process, including characteristics of suitable modelling tools, model application to decision making, approaches to model formulation and setting assumptions, methods to cross check data etc. (Voinov and Gaddis, 2008).

When characterising a PM project, the literature suggests specifying an overall *purpose* of a project; an approach for design and implementation of a *participatory process*; and characteristics of a *model* and other methods used in the project (Hare, 2011). Thus, project purposes can be classified as decision making, collaborative learning and mediation (Basco-Carrera et al., 2017). Participatory processes can be characterised in terms of level of participation and type of cooperation within a PM process (Basco-Carrera et al., 2017) or degree of stakeholder involvement, diversity of the stakeholder groups involved or group size (Voinov and Gaddis, 2008). Models can be subdivided into analytical, data-driven and optimisation types (Basco-Carrera et al., 2017).

Reported effects of PM processes are similar to those reported for PB projects. They include *support of collective decision making, support of learning processes, facilitation of social learning (Dreyer and Renn, 2011); quality control for better management decisions; higher* levels of *legitimacy of* and *compliance with management decisions* (Röckmann et al., 2012); *acceptance of the models and their results* by policy makers, improved understanding of system interaction and behaviour (Voinov and Gaddis, 2008); *informed environmental decision-making; inclusion of unique and complex knowledge* often held by specific stakeholder groups and stimulation of *cross-sectorial planning* and *recognising trade-offs* on management strategies (Gray et al., 2015).

5. Transdisiplinarity

In this study, we incorporated transdisciplinarity into the process design and implementation of a framework for long-term planning in the heating sector, to achieve more advanced collaboration between researchers and stakeholders and encourage bottom-up initiatives for sustainability transitions. In this work, transdisciplinarity (Td) was understood as "*a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating*

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[*] Definitions adapted from Baldwin and Clark (2000)

knowledge from various scientific and societal bodies of knowledge" (Lang et al., 2012). The Td perspective advances understanding of relations between researchers and stakeholders compared with conventional PM by setting a high level of collaboration within a Td process; stimulates rethinking the roles of researchers in planning processes; provides an approach for process design in a transition context; indicates the value of stakeholder knowledge for scientific process; and stresses the potential of researchers to bring changes in society.

6. Modular participatory backcasting (mPB)

The mPB framework proposed in this study comprises 13 modules, which are described in Table 2 according to the following features: *Goal/Outputs*, *Inputs* (key input modules), and *Examples of methods*.

Table 2. Description of the 13 modular participatory backcasting (mPB) modules

Module	Goal/Outputs	Inputs	Examples of methods
Problem orientation (PO)	Formulation and specification of a problem to be addressed; identification of key challenges	-	Analysis of trends, sustainability assessment of current solutions
System boundaries (SB)	Description of various boundaries of a socio-technical system behind the formulated problem (e.g. spatial, time, socio-political)	PO	Process-based description of a system; life cycle approach
Current situation (CS)	Analysis of the current state of a socio-technical system	PO, SB	Descriptive statistics; causal-loop diagrams
Stakeholder analysis (SA)	Definition of actors that can affect, or can be affected by, the problem	PO, SB	Power-impact analysis, analysis of actor roles, constellation analysis
Needs and functions (NF)	Exploration of current and future system functions and societal needs to be fulfilled	PO	"Why?"-questions technique
Vision (V)	Creation of desirable future vision	PO, NF	Storytelling, brainstorming
Criteria (C)	Definitions and quantification of criteria that specify the vision	V	Brainstorming, quantification
Solutions (S)	Generation of a complete solution space	V, SB	Storytelling, Morphological method
Drivers (D)	Identification of external forces that could impact the system; identification of trends and key uncertainties	SB	Brainstorming, uncertainty-impact analysis, modelling
Solution testing (ST)	Selection of a solution for implementation	S, C, D	Criteria testing, robustness/sensitivity testing; sustainability testing; modelling
Pathway (P)	Elaboration of a set of changes that are required in order to achieve the desirable future vision by	ST, V	Brainstorming, modelling

	means of the chosen solution		
Action plan (AP)	Short-term action-plan in line with the designed pathway	P	Project management techniques
Follow-ups (F)	Design of follow-up activities and initial monitoring of implementation of the project outcomes	P, AP	Brainstorming; follow-up interviews

When exemplifying the methods that can be applied within the modules, only analytical and design methods are provided. To follow the classification of PB methods suggested by Quist et al. (2011), participatory and management methods are also connected to the mPB. In this study these methods are implemented according to the principles of Td.

7. Design and results of mPB

The mPB was implemented in two cases aimed at sustainability of heat provision in cities with relevant adaptations to the local socio-cultural context and project limitations (e.g. time, skills, budget). The first project was performed in the Ukrainian city Bila Tserkva during January 2012-May 2013 and the second in the Serbian city Niš during January 2014-May 2015. Besides identified differences, both cities have a number of similarities such as a dominant top-down mode of energy planning with a short-term planning horizon; high priority given to techno-economic criteria and almost neglecting environmental and social criteria; poor condition of many technical components; lack of cooperation between researchers and stakeholders; and lack of locally available knowledge and skills to advance energy planning practices.

7.1 Bila Tserkva case

Bila Tserkva is a medium-sized city with a population of 220 000 located in central Ukraine, 80 km from the capital Kyiv. Heat provision in the city mainly comprises district heating (DH) connected to combined heat and power (CHP) based on natural gas. At the time of project implementation, the city’s DH was in rather poor condition, with high losses in the distribution network and in buildings. The decentralised heating system includes individual gas boilers (using a natural gas distribution network in the city), wood stoves and electric heaters. (IEA, 2008; EBRD, 2011)

The project team of the mPB project in Bila Tserkva consisted of representatives from Ukrainian, Swedish and Dutch universities and research institutions. Bila Tserkva city council expressed a willingness to pilot the suggested mPB framework and a broad range of stakeholders from the city were engaged in the project, including representatives of different departments in the city council, the heat generation company, the heat distribution utility, producers of decentralised heating equipment, researchers, NGOs and consumers. Application of mPB in the Bila Tserkva project is shown in Figure 1 in terms of the *efforts dedicated* to implementation of each module and the *shares of efforts through participatory processes and desktop study by the project team.*

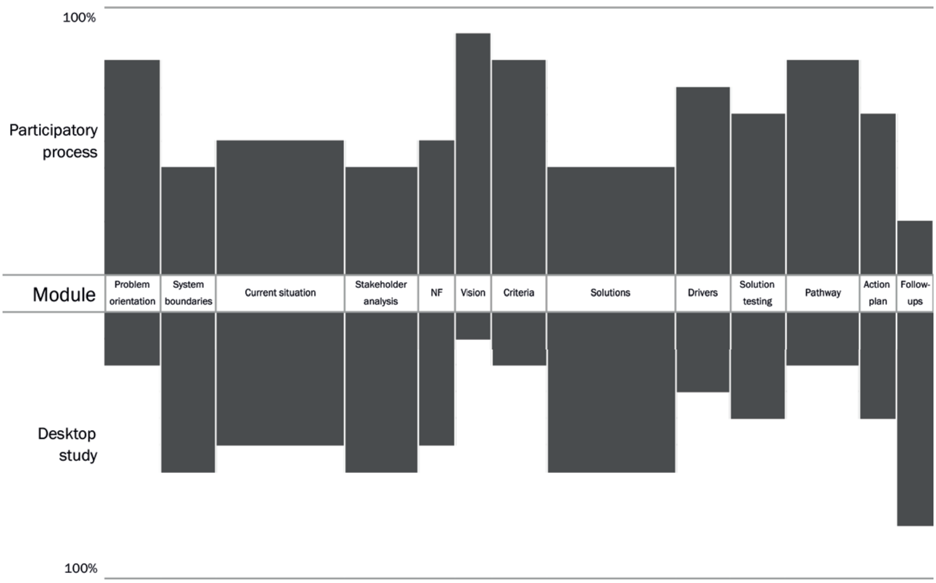

Figure 1. Design of the modular participatory broadcasting (mPB) framework in Bila Tserkva, Ukraine.

The problem for the mPB project in Bila Tserkva was defined in collaboration with local stakeholders. It was decided to focus on sustainability of heat provision in the public, commercial and residential sectors by 2050, with an intermediate point in 2030. System boundaries were defined based on a process-based approach that encompassed different stages of heat provision from the resource input to the final heat demand (an approach based on the European Union (EU) specification for heating systems). The main results for the Bila Tserkva project in terms of future vision, criteria, final solution and key uncertainties are presented in Table 3.

Table 3. Results of modular participatory backcasting (mPB) implementation in Bila Tserkva, Ukraine

Vision	Comfortable indoor climate in residential and public sector buildings
Criteria	Acceptability; affordability; efficiency; environmentally friendly; reliability
Final solution	Fully centralised DH that can supply multi-storey buildings and densely populated areas. DH to be based on natural gas and renewables (heat pump in wastewater was discussed as a possible solution, along with a waste incineration plant). Form of ownership on DH and distribution network set as private, with city council influence. For the private sector and single-family houses, decentralised renewable-based heating solutions are suggested.
Key uncertainties	Prices of energy resources Priority of energy efficiency in national energy policy

7.2 Niš case

Niš is the third largest city in Serbia, with a population of 260 000, and is located 230 km south-east of the capital city, Belgrade. Heat provision in Niš includes DH, with natural gas as the main resource for heat generation. However, a large proportion (33%) of heat consumed in the residential sector is based on electricity generated in a lignite-based thermal power plant. Firewood burned in traditional inefficient woodstoves is the second largest resource for heat generation (31%). The majority of public sector buildings in Niš (about 61%) are connected to DH. (SEAP for Niš, 2014; Statistical office of RS, 2014; Zivkovic et al., 2016)

The project team of the mPB project in Niš consisted of representatives from Swedish and Serbian universities and from Niš city council. The project successfully engaged representatives from a broad range of local stakeholders including different departments of the city council, the DH company, the natural gas supplier, researchers, NGOs and consumers. Figure 2 shows the application of the mPB for the Niš project.

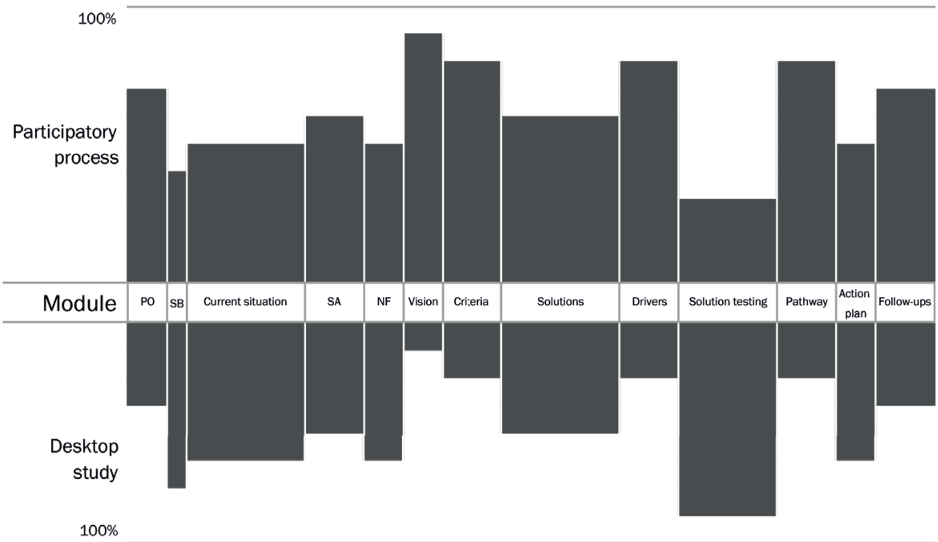

Figure 2. Design of the modular participatory backcasting (mPB) framewrok in Niš, Serbia.

As in Bila Tserkva, the problem in Niš was defined as sustainability of heat provision in the public and residential sectors by 2050, with an important intermediate deadline in 2030. The process-based approach was also applied to define system boundaries. The main results of the project in Niš are presented in Table 4.

Table 4. Results of modular participatory backcasting (mPB) implementation in Niš, Serbia

Vision	Affordable, comfortable and environmentally friendly heating and cooling in Niš by 2050
Criteria	Affordability; comfort/convenience; energy efficiency; environmental performance; energy security
Final solution	Final solution named “Efficiency for the green future”. It includes setting higher standards on energy efficiency of buildings (class B for new and class C for retrofitted). Maximal expansion of DH in the central part of the city and zones with high heat load density, and marginal expansion of DH in zones with low heat load density. The scenario assumes a major increase of the share of renewables for both DH and decentralised solutions. It also gives priority to green

	architecture solutions for new buildings in the city (e.g. green walls, bio-degradable materials, building placement etc.). Furthermore, the scenario includes the application of smart technologies (e.g. meters, sensors, IoT) in new buildings.
Key uncertainties	Economic development Political will for change in the energy sector at national level

8. Discussion and Conclusions

The study proposes a novel framework for long-term planning in the heating sector: modular participator backcasting (mPB). It is based on *participatory backcasting* (Quist et al., 2011), which assumes development of a desirable future vision and a pathway towards this vision. The PB approach enabled engagement of a *broad range of stakeholders* in both case cities and facilitated workshop interactions based on *consensus building*. It also allowed *sustainability* criteria to be incorporated into both projects through stakeholder dialogue during the creativity workshops. Furthermore, *the planning horizon* was considerably *prolonged* compared with that typically used in both cities.

The design of mPB based on the principle of *modularity* strengthened its adaptability and scalability. Thus, in both projects, the order of the modules, the amount of effort dedicated to each module, the effort distribution between the participatory activities and the back-office work by the project teams, and the methods within the modules were adjusted to the local context and project limitations. Furthermore, modularity *facilitated learning* on mPB by local researchers and stakeholders and helped them apply their skills and experience to strengthen the quality of the module outcomes.

The property of *augmentation* provided the possibility of adding modules to mPB. In both Niš and Bila Tserkva, a number of capacity-building workshops were integrated into mPB as additional activities for local researchers. Adding other modules focusing e.g. on networking or learning could be beneficial for strengthening the corresponding effects of mPB. The property of *exclusion* provided an opportunity to integrate results achieved within other projects. For example, the *Current situation* module was partly based on outcomes from other projects (e.g. SEAP for Niš). The property of *substitution* was used to integrate different methods into the same modules. Thus, in the Niš project *Solution testing* was facilitated by the development of a model in LEAP (Long-range Energy Alternatives Planning System), while in Bila Tserkva project the same module was implemented through expert analysis by stakeholders.

In both projects, quantitative methods were integrated into the participatory processes. This PM-inspired approach led to a number of positive effects, e.g. enhanced quality of solution analysis against environmental criteria, operationalisation of criteria to enable their use as progress indicators, and in-depth current situation analysis. In the Niš case, questioning of the assumptions for the LEAP model through the participatory process was beneficial in model improvement. However, the projects also confirmed challenges related to PM. To address some of these challenges (e.g. the ‘group think’ effect and influence of human biases), the *morphological method for scenario development and selection* has been integrated into the *Solutions* module (Pereverza et al., 2017). Further development of such methods for other modules could be important for strengthening mPB.

Incorporation of principles of Td into design and implementation of the mPB led to establishment of more equal relations between researchers and stakeholders, and facilitated creation of a supportive environment for knowledge sharing and co-creation activities. Both projects had positive influences on the attitudes of participants regarding the importance of collaboration between researchers and stakeholders to foster sustainability transition in Ukraine and Serbia.

Overall, implementation of mPB contributed to the reproducibility and transparency of long-term planning processes in the heating sector. This is beneficial for advancement and democratisation of local planning and policy-making practices and for further research through cross-case analysis.

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Energy Performance Certificates — New Opportunities for Data-enabled Urban Energy Policy Instruments?

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Abstract

European Union (EU) building codes require generation of energy performance certificates (EPC) for all new buildings and major renovations. The aim of these certificates is to help member states reach the energy efficiency targets set by the EU, by visualising energy efficiency opportunities for building owners. EPC data provide opportunities for future energy policies, monitoring of building energy performance and energy efficiency market research. However, to exploit these opportunities, good quality and coverage of EPC data are required. Conventional data quality studies while focusing on data accuracy and consistency, do not expose all problems that limit effective use of the EPC data, e.g. lacking features, poorly developed metadata, etc.

This paper proposes a novel method for assessing the quality of EPCs using data analytics. The method is based on six validation levels and is empirically exemplified with a study of the city of Stockholm. Three versions of an EPC dataset were analysed, highlighting typical problem areas and approaches to problem identification and mitigation. Existing applications of EPC data were classified by types of data science research questions. The analysis showed that EPC data can be improved through a) adding or revising the EPC features and b) assuring interoperability of EPC datasets. The study concludes that EPC data can have wider applications than initially intended by the EPC policy instrument, which would put stronger requirements on the quality and content of the data.

1. Introduction

The buildings sector is the largest consumer of electricity and district heat (International Energy Agency, 2016), accounting for 19% of energy-related greenhouse gas (GHG) emissions globally in 2010 (Lucon et al., 2014). Thus it is also one of the most cost-effective sectors for reducing energy consumption (International Energy Agency, 2010). Decreasing overall energy demand and improving energy efficiency in buildings without compromising comfort, health and productivity is the basic strategy for decarbonisation of this sector.

Regulations, audits and certification are three basic policy instruments for energy efficiency in buildings (Pérez-Lombard et al., 2009). Energy performance certificates

(EPCs) have emerged as a core instrument for achieving energy efficiency in buildings since the early 1990s. The general idea behind EPCs is to influence the building market through informing actors in the building sector (building owners, occupants, real estate agents etc.) about the energy performance of buildings (Maldonado, 2015). As the term ‘energy certification’ has a slightly different meaning across various implementations, here we use the International Energy Agency (IEA) definition, which includes a) the entire process of certification (the assessment), b) the result (the certificate) and c) dissemination of the information (International Energy Agency, 2010).

Over the 10-year period since European Union (EU) member states first launched the EPC data collection process, the EPC database has become one of the main sources of information about building energy, but certain concerns have been raised about its quality (Arcipowska et al., 2014). The performance gap, i.e. the difference between estimated and actual energy performance (de Wilde, 2014; Kelly et al., 2012; Majcen et al., 2015), may be preventing the adoption of bottom-up energy efficiency measures (Kelly et al., 2012). Swedish EPC data are no exception since: they may contain uncertainties (Claesson, 2011); the estimated average variance of Swedish EPCs is ±20% for energy consumption assessment and ±80% for energy conservation potential assessments (Hårsman et al., 2016); and detailed discrepancies have been reported for the building areas featured in EPCs (Mangold et al., 2015).

The current exponential increase in available building energy and environmental monitoring data (Ahmad et al., 2016) is generating great potential for applications based on data science — a fusion of mathematical and statistical analysis with information technology tools for extracting and exploiting the knowledge and information contained in data. Data analysis techniques have been shown to be useful for solving energy problems (Molina-Solana et al., 2017). Yet, as with any other scientific method, the quality of the input data and research questions being answered are crucial for the quality of the results. Recent studies point to a wider spectrum of possible applications for EPC data than originally intended, for instance in studies of energy demand in buildings and related causalities (Brøgger and Wittchen, 2016) and in creating overview and validating models of the building stock (Mangold et al., 2015).

EPC data can add value for policy making, monitoring, market and research analysis, but for such applications further quality measures should be introduced and effective use of the EPC data should be promoted (Arcipowska et al., 2014). Existing EPC data quality studies usually focus on data accuracy and consistency issues, which do not cover all levels of validation (Simon, 2013). Although data quality studies provide valuable feedback to EPC data collectors, they do not expose all the data quality issues that prevent broader application of the EPC data.

The aim of this study was to identify the possibilities and problems for utilising the EPC data in the building energy studies, based on a literature review, and to demonstrate a new approach to EPC data quality assurance for the case of Sweden.

2. Building energy

The energy performance of buildings is a major focus of the EU's energy and climate policy. The primary instrument for improving building energy performance in the EU is the Energy Performance of Buildings Directive (EPBD), which was introduced in 2002 (EPBD 2002/91/EC) and revised in 2010 (EPBD recast 2010/31/EU). The necessary improvements are to be achieved through various approaches, e.g. imposing new building codes for newly constructed buildings, energy retrofitting of existing buildings, developing financial incentives to foster energy efficiency, shifting consumer behaviour etc.

Building energy certification has been developed as a key policy instrument to improve energy efficiency, decrease energy consumption and provide more transparency on energy use in buildings. Besides national certification schemes that have been developed, first in the EU and US and later in other countries, a number of regional and global schemes have appeared, e.g. BREEAM, LEED, Miljöbyggnad, Svanen etc. Pérez-Lombard et al. (2009) distinguish three processes within building energy certification: (i) benchmarking, (ii) rating and (iii) labelling. However, Nikolaou et al. (2011) propose five certification procedures: (i) benchmarking, (ii) building database, (iii) energy efficiency estimation, (iv) determination of energy classes and (v) improving energy efficiency.

EPC data generally include: a) building reference (identification, type, construction year), b) building geometry (floor area, envelope form), c) certificate methodology (measured vs calculated data, time period of the audit), d) factual energy consumption (energy use per source), e) calculated energy performance, f) energy system installations (HVAC, solar), g) recommendations (and their implementation), h) additional information (reference values, emissions) and i) energy expert information.

By 2014, quality control of EPCs was established in all EU member states. Although approaches vary among different countries, all of them involve verification of "a random selection of at least a statistically significant percentage of all the energy performance certificates issued annually" (EU Parliament, 2010). Arcipowska et al. (2014) highlight a need for further improvement of EPC data quality, including use of intelligent tools for quality checking and further harmonisation of the quality checks on EPCs.

3. Reproducible data analysis

Rapid development of ICT and the consequent data deluge has triggered the emergence of data-driven and data-intensive research (Hey et al., 2009). Digitisation of cities and the growing ubiquity of data has resulted in intensive development of massive datasets and data streams related to the urban environment (Kitchin, 2014). This opens up new opportunities for urban and building energy studies, e.g. using data science for building energy management (Molina-Solana et al., 2017). At the same time, it imposes higher standards on urban analytics studies from the perspective of reproducible research (Peng, 2011).

Data quality is a basic requirement for the validity of data-driven research (Osborne, 2013). Data producers may play an important role in providing official quality thresholds for the published data ('truth-in-labelling'), yet the main responsibility for assessing whether the data fit the particular application lies with data consumers, who determine their final 'fitness-for-use' (Veregin, 1999). Problems with data accuracy, precision, consistency and completeness can be addressed by data cleaning methods, which include screening, diagnosis and editing (Van den Broeck et al., 2005). Although many data problems can be occasionally detected within analysis, searching for errors in a planned way is more efficient and secure.

To arrange screening of the EPC data in a systematic process, we suggest the use of data validation levels (see Table 1). Each increase in level corresponds to use of larger amounts of data in the analysis. Validation on levels 3-4 is possible only if there are additional related datasets available from the same data collector, and is therefore usually performed only by the data collector, while validation on levels 3-5 usually demands significantly more efforts to enable connectivity between the datasets analysed. This limits most EPC data quality studies to validation levels 0-2.

Table 1: Data validation levels (adapted from (Simon, 2013)

No.	Validation level	Description
0	Data structure	Check of format and structure (no data)
1	Within the file/table	Checks between cells, records, aggregate statistics
2	Within the dataset/source	Checks between file revisions, time series
3	Within the domain	Mirror checks between different sources
4	Within the data collector	Consistency checks between domains
5	Between data collectors	Consistency checks between data collectors

Even fully reproducible data analysis can be erroneous if the wrong type of question is addressed. In this paper, we map applications of the EPC data using the typology of data analysis questions proposed by Leek and Peng (2015): 1) descriptive, 2) exploratory, 3) inferential, 4) predictive, 5) causal and 6) mechanistic.

4. Applications of EPC data

Using the typology of data analysis questions (Leek and Peng, 2015), recent studies that used EPC data and applied or had clear potential for applying data science techniques for analysis of building energy were classified (Table 2).

Table 2: Classification of existing EPC data applications by type of data analysis questions

Problem	**Type of data analysis question** (**D**escriptive, **E**xplanatory, **I**nferential, **P**redictive, **C**ausal, **M**echanistic)	**References**
Building energy use		
Mapping existing building stock performance	D, E	(Hjortling et al., n.d.), (Yang and Chen, 2016), (Johansson et al., 2017)
Building energy use	P	(Yu et al., 2016), (de Wilde,

prediction		2014), (Herrando et al., 2016), (Mangold et al., 2015), (Paterson et al., 2017)
Study of determinants of building energy use	D, E, I, P, M	(Hawkins et al., 2012)
Economy of energy performance		
Effect of EPC rating on the capital values of assets	D, E, I	(Fuerst and McAllister, 2011), (Jensen et al., 2016)
Cost-efficient retrofitting	E, P	(Jeong et al., 2017)
Consumption behaviour		
Building occupancy and occupant behaviour	D, E, P, C	(Yu et al., 2016), (Majcen et al., 2015)
Building energy management		
Fault detection diagnostics (FDD) for building systems	D, E, I, P, C, M	(Yu et al., 2016), (Molina-Solana et al., 2017)
Building design & renovation		
Design of low-emission/energy buildings	D, E, I, P	(Molina-Solana et al., 2017), (Johansson et al., 2016), (Ladenhauf et al., 2014)
Energy retrofitting	E, P	(Dineen et al., 2015), (Johansson et al., 2017)
Energy planning		
Energy planning at the municipal or district level	D, E, P	(Dall O et al., 2015), (Johansson et al., 2016)

As Table 2 shows, some of the EPC data applications have a clear connection to the initial goal of the EPC instrument (e.g. mapping the current building stock performance and benchmarking the design of newly constructed buildings), while other applications go beyond these objectives. It is also worth pointing out that in most of the cases listed in Tab/e 2, merging of several data sources created the greatest added value.

5. Analysis of Swedish EPCs

In Sweden, EPCs were introduced in 2006 by the Energy Declaration Act. The Board of Housing, Building and Planning (Boverket) is the body responsible for legal regulation of EPCs, their supervision and quality, including maintenance of the EPC database “Gripen” and involvement of independent certified experts. EPCs are mandatory for all buildings that are: a) subject to sale or rent; b) frequently visited by the public; or c) newly constructed. The basic EPC data (e.g. energy use intensity, ventilation check, local contact point and date of the declaration issue) are available to the general public on the Boverket website,[1] through a search by declaration ID or building address, while the remaining information on a particular building can be obtained by request from real estate agents, building owners, occupants, maintenance companies or other interested parties (after the necessary data anonymisation).

[1]http://www.boverket.se/sv/byggande/energideklaration/sok-energideklaration/sok-och-bestall-energideklaration/

In this study we analysed three versions of the EPC dataset (Table 3) using metering data on factual heat energy consumption in Stockholm[2] obtained from the local energy utility (AB Fortum Värme Samägt med Stockholms Stad) operating the city's district heating network.

Table 3: Versions of the EPC dataset analysed in this study

No.	Date of latest record	Number of EPCs		Distinguishing features *(see Notes below)*
		Sweden	**Stockholm**	
1	11 Nov 2009	190 067	14 117	(e)
2	10 Apr 2014	-	15 947	(a), (c), (d)
3	31 Dec 2016	596 050	30 476	(b), (c), (f), (g)

Notes:

a) *Data are subset to the City of Stockholm.*
b) *Columns on ventilation systems are absent.*
c) *Information on the contact responsible for energy efficiency is absent.*
d) *Recommendations on energy efficiency measures are absent.*
e) *Recommendations on energy efficiency measures are provided in free form (text field).*
f) *Recommendations on energy efficiency measures are provided in logical form (checkboxes).*
g) *New building usage typology is used from 2015.*

The dataset on factual district heat energy consumption (hereafter 'FDH') contained data on heat energy consumption at 15 068 metering points representing all buildings in Stockholm that are customers of the local district heating network, which corresponds to ~85% of the total building stock in the city. The data covered the year 2012 with hourly precision and also contained reference information on type of building usage, building age category and total heated area (A_{temp}).

In our analysis we applied a quality assurance approach using five validation levels (Table 1): 0) data structure; 1) within the file/table; 2) within the dataset/source; 3) within the domain; 4) within the data collector; and 5) between data collectors. Validation at levels 0, 1, 2 and 5 was conducted within the scope of urban energy modelling for city-wide retrofitting planning for Stockholm. Validation at levels 3-4 was not performed directly in this study, due to lack of the necessary data, but results in other studies and possible approaches are described for levels 3 and 4, respectively.

<u>Level 0. Check of the data structure.</u> We explored the format and structure of the dataset. All three versions of the dataset (Table 3) were exported manually from the SQL database by Boverket representatives into a similar format of text file with separators. The metadata did not contain information on which columns are compulsory. Therefore missing values were treated by the data-inspired rules constructed for each column individually, as recommended by (Graham, 2009). For some columns missing values could be converted to zero values or imputed from related cells with strong confidence (as in the case of different types of area), while for other columns missing values could be interpreted only as NA (not available).

We concluded that limiting missing values during data collection and making a clear distinction between zeros and NAs in the database would allow possible confusion to be avoided and would preserve more information.

[2]Stockholm municipality is referred to hereafter as "Stockholm".

Level 1. Check between values and records. This type of validation is the most widespread. We performed several types of consistency checks:

i) Constraint rules for particular columns (e.g. area cannot be negative, municipality name should be in the dictionary).
ii) Physical rules involving analysis of values from several columns (e.g. year of construction cannot be later than date of declaration approval; if electricity intensity use is above standard threshold and there is no reported heat source, then unreported heat pump usage is assumed).
iii) Statistical checks (outlier analysis (Aggarwal, 2016) and aggregate statistics tests (US EPA, 2000))

The analysis showed that linking dictionaries and adding constraints would significantly improve the quality for most string and numerical types of columns respectively.

Level 2. Check between dataset revisions. We conducted comparative analysis of the three dataset revisions (Table 3) which allowed us to: a) follow the general dynamics of dataset development; and b) reveal the uncertainty in particular features (columns) or particular EPCs (records). For example, it was shown that 22 348 (11.8%) EPCs from the dataset v1 are not present in the dataset v3, which cannot be explained by re-audit of these buildings in all cases. While general dataset structure has been kept the same, many column names have been changed and some columns have mutated quite dramatically (see distinguishing features in Table 3), which adds additional replicability problems to EPC data applications.

The analysis demonstrated that data representation of the building stock in the form of non-linked building ‘snapshots’ carries a risk of significant loss of data consistency over time, which limits studies of the dynamics of the building stock. We suggest that a) database structure changes should be documented and made available to the public; and b) a ‘connected timeline’ approach should be applied, appending updates to each building record instead of rewriting it.

Level 3. Check between data sources. We did not perform quality assurance within the EPC domain due to the limitations of this study and instead analysed the results of the study performed by (Claesson, 2011) in collaboration with Boverket. That study evaluated the data quality of Swedish EPCs focusing on the stage of data collection and input by energy experts. Ten randomly selected EPCs were assessed via independent energy audits and interviews with the energy experts. Claesson (2011) found: a) clear misuse of measured and estimated values on energy use; b) error values produced by ‘take the rest’ principle when the remaining energy use component was calculated without measurement; c) limitations of the “normal” energy use used for comparisons; d) loss of information about the recommendations due to not including them in the declarations; and e) lack of uncertainty estimation for reported values analysed.

We concluded that a) training and quality control of the experts producing energy declarations should be a priority for EPC data quality assurance on the data collection side; b) addition of anonymised data on the energy experts to the dataset would allow researchers to perform independent quality control of the experts through data analysis; and c) the structure of the recommendations section should be revised to maximise the useful information collected from the energy audit.

Level 4. Check between domains. We did not perform this validation due to the limitations of this study. Validation between various domains within the same data collector (Boverket) is possible through analysis of the datasets collected for other tasks of Boverket. As Boverket is responsible for national financial support to the buildings sector, planned and reported energy-related costs is an adjacent domain for consistency check of energy performance indicators. Construction permits is another domain to provide check data on general building characteristics within the same data collector.

We concluded that EPC data collectors usually have a number of data streams from adjacent domains which can be used for validation at level 4. Due to the privacy limitations and interoperability challenges, this should be performed by the data collector rather than a third party.

Level 5. Check between data collectors. We performed level 5 validation through linking the Stockholm subset of EPC data with FDH data via cadastral codes *('fastighetsbetäckning'* in Swedish). That allowed us to conduct a consistency check of columns present in both datasets (heated area, heat energy use intensity, building usage category, building age). We observed a slight discrepancy between all data fields, with major problems regarding heated area (A_{temp}). An additional random check through Google Maps Street View allowed us to confirm errors in reported number of floors in the EPC data.

Besides quality assurance at this level, the EPC data were used:

a) to segment the Stockholm building stock into archetype clusters within a city-wide retrofitting data analysis; and
b) to inject additional controlled parameters into the FDH data for dedicated studies of the performance of particular energy systems and retrofitting solutions.

The main obstacle to EPC data application was that the amount of EPC data initially linked to FDH data was rather low (47.6% of all eligible records) and the share of the valid linkages that passed checks was even lower. This is mainly due to non-completeness of both EPC and FDH datasets providing rich, but not full, coverage of the examined building stock. Adding a third data source without this problem, e.g. a dataset on cadastral codes from the Swedish National Land Survey (Lantmäteriet), would help to solve this problem.

We concluded that application-driven quality assurance: a) is less holistic and by default cannot provide full coverage of the quality issues, as the primary goal of the study is different; and b) sets stronger requirements on the EPC data and consequently can result in generation of more insights regarding further requirements on this dataset.

6. Discussion & Conclusions

This paper demonstrates a new approach to systematic data assurance of the EPC data based on five different validation levels. The proposed data quality assurance procedure can be used both in initial data quality control by the data collector (e.g. Boverket) and at the stage of data cleaning and editing by individual data users (e.g. researcher. The former is reported to be by far the cheaper option (Chapman, 2005). Swedish EPC data can be commended for their representative coverage of the national building stock by 2016, well-established structure and digital organisation, active quality assurance measures and quite open mode of access for wide public, but there is room for improvement.

The EPC data can be used for the vast majority of building energy studies, i.e. building energy use analysis and prediction, design of new buildings and energy- and cost-efficient retrofitting of existing buildings, occupant behaviour and building operation, where EPC data quality is significantly application-driven. Redesigning building performance evaluation and certification tools so that they target specific policy objectives may increase their effect (Kelly et al., 2012). The FAIR (findable, accessible, interoperable, usable) guiding principles for scientific data management and stewardship (Wilkinson et al., 2016) could be used to steer such redesign from a data management perspective.

Adding and improving features of EPCs is one possible direction for improvement. For example, Swedish EPCs could also provide information on transparent and opaque areas, as envisaged by the general EPBD requirements and as implemented in other national EPC databases (Dascalaki et al., 2010; Sustainable Energy Ireland, 2006). Such improvements would make possible automated building simulation workflows for urban building energy modelling. Assuring interoperability and transforming data structure in compliance with the linked data standards (Abanda et al., 2013) is another core area of improvement. Moreover, it has been demonstrated that preserving primary data at disaggregated level is required (Brøgger and Wittchen, 2016).

Linking the EPC data to FDH data in this study demonstrated the benefits of validation based on the independent sources. Similarly, Kelly et al. (2012) concluded that using metered energy consumption data can improve the accuracy of EPCs and related applications. The linking of EPC and FDH data sources in this study benefited the city-wide retrofitting planning for Stockholm, which confirms the reported need for interoperability of the EPC dataset with other data sources (Hårsman et al., 2016).

It is clear that EPC data can have wider applications than initially intended by the EPC policy instrument. The benefits of using EPC data for a broader scope of applications are twofold: i) it sets stronger requirements on the quality and content of the data and ii) growth in applications apparently triggers more feedback, enabling easier means of quality control, and increases the general effect of the EPC instrument. In the present study, classifying building energy problems by type of data analysis research question proved helpful for identifying needs and providing systematic guidance for the development of EPC databases, along with highlighting unrevealed potential for EPC data applications.

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Energy features of human Socio-Ecological Systems relevant to the future of civilization

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Abstract

The paper, which assesses the basic thermodynamic properties of a human Socio-Ecological System (SES), is aimed at analyzing the societal evolution and vulnerabilities, given its main energy features. The costs for maintaining a hierarchical structure, which developed historically under the pressure of different emerging threats, are payed by the lower levels (i.e.: the components) of the society and by the biota. In particular, the increasing level of energy demand is forcing human SESs to move toward undesirable tipping points, which are well described within the planetary boundary framework. In order to avoid such an unwished transition, a multi-dimensional approach should be adopted. The redistribution of energy demand, the economic implications, the preservation of the natural biota and of biodiversity should be focal points for developing and adopting future policy roadmaps. Further investigations are also necessary, in order to better understand the energy dynamics associated to human SES structure for reducing the potential risk of a future societal collapse. Finally, the growing body of literature on sociotechnical transitions could provide a source of ideas to assist in this task.

1. Introduction

We live in the Anthropocene, the epoch in which human activity profoundly affects the environment, from Earth's major biogeochemical cycles to the evolution of life (Lewis and Maslin, 2015). There is a distinct geological evidence, indicating that this new geological era started with the so-called 'Great Acceleration' of the mid-twentieth century (Zalasiewicz et al., 2015; Waters et al., 2016). The intensive growth of population, GDP and productions constitute some of the basic features of the Great Acceleration. Thus, our future environment will largely consist of human-influenced ecosystems, managed to varying degrees, in which the natural services, that humans depend on, will be harder and harder to maintain (Palmer et al., 2004). This new situation calls for a fundamental shift in perspectives, world views, and institutions (Folke et al., 2011). In particular, human development and progress must be reconnected to the capacity of the biosphere and essential ecosystem services to be sustained.

This is why a conceptualization of human communities and their dynamics is fundamental. In particular, we need to understand how to describe the 'dialogue' on human/nature relations, including both the social and natural sciences. Hence, the integrated functioning of individual system components and the driving forces of human and natural origin need to be analysed together. Earlier attempts to develop an ecological framework for integrating humans with nature were developed by Vladimir Vernadsky and Pierre Teilhard de Chardin, who defined the concepts of biosphere and noosphere (Levit, 2000). A few decades later, the opportunity of investigating life (Schrödinger, 1992) and societies (Majorana, 1942) through a physical approach was explored. In particular, the paper by Ettore Majorana recognizes the value of statistical laws for describing the properties of social processes. Later, Social-Ecological Systems (SES hereafter) theory was developed, as the "integration of the parts" (Holling, 1998). A SES, which is complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context, can be broadly defined as (Glaser et al., 2008): a coherent system of biophysical and social factors, that regularly interact in a resilient, sustained manner; a system that is defined at several spatial, temporal, and organisational scales, which may be hierarchically linked; a set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; a perpetually dynamic, complex system with continuous adaptation (Berkes et al., 2003).

A hierarchical understanding of biological systems is not new, since it has prevailed among biologists for more than a century. At the same time, as a consequence of works by Schrödinger and Prigogine, thermodynamic views have been imposed on ecosystems (Nielsen, 2000; Jørgensen and Nielsen, 2015). Nonetheless, the integration of environmental, social, cultural and economic dimensions within a unique methodological framework and a unified nomenclature is still at its beginning for a human-dominated system. This is why a new conceptual model was developed by Casazza et al. (2017), in analogy with molecular structures, using the physical chemistry as a reference language. The analogy is rooted on two basic properties of living beings: their connected and finite structure and their need for energy (Sertorio and Tinetti, 2001). Starting from these premises, on the basis of a few properties known from thermodynamics, which will be described in the next section of this work, the purpose of this paper is to further investigate the properties of a human SES, while discussing about its stability and the potential arising vulnerabilities. Energy instability is viewed as one among the possible causes of societal collapse (Tainter, 1988). The discussion will investigate about the societal consequences derived from such attributes focusing on: societal evolution; societal stability; risk of collapse and vulnerability; vulnerability of the biota; possible solutions. Some conclusions will be drawn in the final section, based on the given evidences.

2. Materials and methods

The energy-related properties of a human SES are briefly listed in this section. They can be defined using thermodynamics and statistical mechanics, since it is demonstrated that a homeomorphism exists between ecological systems and statistical mechanics (Rodríguez et al., 2012). A human SES is a multi-level structure, which can be described through a set of different parameters. Each level of the structure goes through different microstates, which can be quantified. In this framework, the nature of boundaries within hierarchy theory has been already investigated elsewhere (Yarrow and Salthe, 2008). The possibility of defining and measuring independently the characteristics of each microstate, as sub-systems of a given system, depends on the statistical independency, which is not intuitive, since they are not isolated. Nonetheless, being microstates both macroscopic and smaller than the whole system, they can be treated as separate for sufficiently small time intervals (Landau and Lifshitz, 2013). This means that the state of a micro-system doesn't affect the probability of measuring different values and observing different dynamics for the other microstates. This property is known as statistical independency. The statistical independency of microstates guarantees the validity of Liouville theorem and, as a consequence, the basic properties of each microstate can be expressed as first integrals as a function of energy. This is true for sufficiently short time intervals. Otherwise, the thermodynamic criteria come from non-equilibrium or irreversible thermodynamics. These facts are confirmed in a study, which claims that, during periods in which the boundary conditions may be considered as being constant, criteria from irreversible thermodynamic theory are sufficient to permit a quantitative prediction of ecosystem response to perturbation (Chávez and Michaelian, 2011).

Second, in order to describe the equilibrium of a non-isolated system, Gibbs free energy (also known as availability or exergy), usually labelled with the letter G, was introduced. G is defined through the following equation:

$$G=E+pV+\mu N - TS \quad (1)$$

It is possible to describe the terms appearing on the right hand-side of the equation in simpler words with respect to the purpose of this paper. The term E represents the internal energy, which is a 'structural' variable, used to quantify the energy invested in keeping together a structure composed by N elements. The product of p and V measures the (mechanical) work performed by the system. The product between μ and N assesses the accumulation of energy by the N components of the microstate on the basis of individual energy attribution, measured through the variable μ. Finally, the last term, weights the loss of the sub-system in relation with dissipation.

Gibbs described this "available energy" as "the greatest amount of mechanical work which can be obtained from a given quantity of a certain substance in a given initial state, without increasing its total volume or allowing heat to pass to or from external bodies, except such as at the close of the processes are left in their initial condition" (Gibbs, 1873). The equation describing the process associated to Gibbs free energy changes simply says that, when the energy associated to the structure is consumed along a time interval, a certain amount of power is dissipated and the balance is maintained by the change in performed work (Annila, 2010). A remarkable property of G is that, for a system with constant (external) temperature and pressure, the equilibrium state corresponds to a minimum of Gibbs free energy (Huang, 1987). In general, this means that:

$$\Delta G \leq 0 \quad (2)$$

The use of G is convenient, when considering biological evolution in terms of thermodynamics, because many organisms can only live in a comparatively narrow range of temperatures (T) and pressures (p). Thus, for a first approximation, T and p can be considered constant. Furthermore, each process of reaching quasi-equilibrium in a subsystem (system) can be regarded as a particular biological evolution, which is a component of the general biological evolution (Gladyshev, 1978). The introduced concepts allow one to speak of "quasi-equilibrium states" in complex subsystems (systems) and to use the general methods of the classical theory of equilibrium (Gibbs, 1928; Guggenheim, 1933; Lewis and Rendall, 1961). Note that in non-equilibrium thermodynamics quasi-equilibria can be described as 'asymptotic stationary states of imbalance" (Prigogine & Defay,1954; Prigogine, 1959). General features of G, which can be applied for the description of population evolution and even the noosphere, which is associated to human information flows, is further described in some later papers by the same author (Gladyshev and Gladyshev, 1996; Gladyshev, 2002a; 2004; 2007). Among them, the hierarchizing process, within a given ecosystem at any scale, as a function of G is assessed.

Three further properties are assessed in Gladyshev works (Gladyshev, 1978; 2007): (1) The existence of evolutional potentials as analogues of chemical potentials, defined as specific components of the Gibbs free energy related to the unit mass; (2) The increase of energy density in the volume V of any evolving biological subsystem, in association the increase potential (e.g.: considering the use of technologies and humans as a whole and combining the growth of the parts; Gladyshev, 2007); (3) The increase of higher-hierarchy formations stability, due to the enrichment of subsystem with substances having a high energy capacity; (4) During the formation or self-assembly of the most thermodynamically stable structures at the highest hierarchical level (e.g.: the supramolecular level, Nature), in accordance with the second law of thermodynamics, spontaneously uses predominantly the least thermodynamically stable structures available from a given local part of the biological system, belonging to a lower level (e.g.: molecular level), while incorporating these unstable structures into next higher level (e.g.: supramolecular level) (principle of hemical substance stability). The latter principle is derived from the second law thermodynamics (the Clausius–Gibbs variation) in coordination with the Le Chatelier–Braun principle (Gladyshev, 2007).

Some independent findings are of interest in confirming the previously described properties. In particular, the evidence of a hierarchical network of energy transformation processes, which joins small scales to larger scales, and these to even larger scales, emerged in the works by H.T. Odum. Available energy (i.e.: Gibbs free energy) at one level is used up in each transformation process to generate a smaller amount at the next larger scale. Self-organisation reinforces designs, in which the higher quality energies on the right feed back to the left to reinforce the input process (autocatalytic feedback). Thus, the use of emergy (spelled with ‘m’), as the available energy of one kind previously used up to make it, entered in the description of ecosystem dynamics (Odum, 2002a). Furthermore, emergy was used to identify and explain the results as systems designs and hierarchical structures self-organized for maximum empower. In particular, systems self-organize designs and populations that maximize their contribution to the empower (i.e.: emergy with respect to time) of the surrounding system (Odum, 2002b). More in detail, the maximum empower principle is a re-statement of Lotka’s Maximum Power Principle (Lotka, 1922) into a more suitable Maximum Empower Principle, according to which the simultaneous maximization of empower (emergy throughput flows) at all system’s levels is required for sustainability (Ulgiati, 2004). Such a growth is described as increase of potential in the works by Gladyshev. The growth of individual power extraction, considering the contribution of the technologies as an additional term of human metabolic power, is visible along human civilization (Casazza et al., 2016). This process of accumulation was theorized by Gladyshev and confirmed by the maximum empower principle. The presence of the noosphere, whose definition should be reframed into the ‘sphere’ of information, is also considered in the works by Odum (Odum and Odum, 2001). Finally, the principle of substance stability, applied to the biota and for human-dominated ecosystems, was confirmed independently by other research scholars (e.g.: Gorshkov, 1995; Makarieva et al., 2005; Makarieva et al., 2014). The mentioned law of substance stability, as a form of the second law of thermodynamics, can be also described as a general case of the principle of least action (de Broglie, 1970). Hierarchical organization of ‘systems within systems’, universal patterns (such as power-law dependences, skewed distributions, tree-like structures, networks and spirals), optimization strategies in which internal structures change depend on such a principle (Annila and Kuismanen, 2009; Mäkelä and Annila, 2010). Moreover, the action, as the product of energy variation within a given time interval, is minimized along a transformation of the system. As a consequence, temporal hierarchies, which increase in association to an increased position of G hierarchy, depends upon the same rule, which allows to alternatively model energy and time hierarchies (Gladyshev, 2002b).

It is possible to summarize, up to this point, the relevant energy features, which can be applied to human SES: Microstates, such as communities, can be treated as independent components, if a sufficiently small time interval is considered; Gibbs free energy can be used in modelling the dynamics of such sub-components of a SES; Gibbs free energy hierarchy emerge from thermodynamic properties, in accordance to the second law of thermodynamics (i.e.: the least action principle) and to Le Chatelier-Braun principle; There is a natural tendency of potential increase for each microstate. This fact is reflected into the maximum empower principle formulated by H.T. Odum; The validity of emergy accounting and its related algebra, since they are based on the described energy properties of microstates, is confirmed; Emergy and time hierarchies are correlated also through the principle of least action.

3. Results and discussion

As remarked by Sertorio (1992), an ecosystem is thermodynamically living. In particular, the stationary distribution of sustained disequilibria corresponds to a capacity of mechanical power. The ‘gasoline’ for the planet Earth is represented by solar radiation, from which it is possible to extract a certain amount of power embedded in the existing thermodynamic disequilibrium. At the same time, less stable substances, at lower Gibbs free energy hierarchical levels, feed up more stable substances at higher hierarchical positions. Second, human SES display a hierarchy evolution with respect both to time and to energy. This is evident from several historical cases, where complexity is interrelated with energy. The paper by Casazza et al. (2017) introduced a conceptual model of hierarchical energy organization for a human SES. Human SES complexity arises due to several factors. Ecological constraints — such as heterogeneity in time and space, operating costs, and the threat of rupture — may shape the processes used to regulate their activity in many biological systems (Dall et al., 2005). This growth in complexity is closely linked to the growth in energy that is available to power our way of life. Nonetheless, humans have rarely had surplus energy. In fact, surpluses, from whatever source, are quickly dissipated by growth in consumption. This is known as the Rebound Effect, and it has been amply documented (Polimeni et al., 2008). Complexity has energy costs. The cost of complexity is included within emergy, which is the energy of one kind used previously to make a service or product (e.g.: Odum 1996: 7, 26, 265-266). On the other side, also the quality of energy being used to build up a more complex system can be accounted. In fact, H.T. Odum used to describe the energy quality as "transformity". Transformity increases with the energy transformations, that contribute to the formation of a product (Odum 1996:10-11). Obviously, the effectiveness of an investment depends on the obtained gain, which can be evaluated, in energy terms, as "energy return on investment" (EROI) (Hall et al., 1992: 28).

How can the different terms of availability change, when the energy gain declines? The answer is contained in equation (1). As written before, the four terms of which G is composed are: E, pV, μN and TS. Obviously, the main gain is related to the extracted work, pV, which can further transform the microstate. The microstate, in our case, is represented by a human SES. The profit declines within the evolution of a society, when the input is used for different terms than work. Dissipation (TS) always exists, as known from the second law of thermodynamics. Nonetheless, it can increase, due to a decrease of efficiency of a process. Internal energy, E, represents the energy used to keep together a social structure. A sign of collapse for E could be related to the declining investments for keeping together a human community. A few practical historical cases. First, the gradual abandonment of major communication roads, during and after the Roman Empire decline, due to the lack of their maintenance. Second, even if less evident. Symbolic language transformations and/or simplifications. As historical example, the use of Latin was increasingly reduced and substituted with other ones. It is important to remark the recent discovery, which relates language evolution to climate conditions and the number of members of a community (Gavin et al., 2017). Finally, μN represents the sum of individual energy accumulations for the N members of the community. Broadly speaking, this means that transformative energies (i.e.: work) could be diverted into private accumulation of resources. Consequently, both dissipation and energy for keeping a societal structure and private accumulation are competing terms, which might represent a risk for the positive evolution of a society. It is important to remark that, anyway, the terms shouldn't be read as negative a priori. For example, an investment for increasing E means also increasing the public goods and services. Thus, in general, E represents a positive or negative energy social cost. Nonetheless, any expenditure for keeping higher hierarchical levels of a society compel an increase in resource use and, obviously, a certain amount of dissipation. The implication of such a statement will be discussed in the following section.

Which are the costs for maintaining a complex human SES? What is affected by such costs, that represent also a risk for civilization? A general answer, to the first question is derived from equation (1), is given in the previous sub-section, we need to analyse the problem further. Energy costs exist in relation to the availability of resources from lower levels of human SES hierarchy or from the environment. Moreover, it is shown that the environmental impact of the civilization consists, in terms of energy, of two major components: the power of direct energy consumption (around 15×10^{12} W, mostly fossil fuel burning) and the primary productivity power of global ecosystems that are disturbed by anthropogenic activities. This second, conventionally unaccounted, power component exceeds the first one by at least several times (Makarieva et al., 2008). Energy unintended costs, instead, are associated to dissipation and what is generally known under the name of pollution. As the modern industrial-technological-informational economy expanded in recent decades, it grew by consuming the Earth's natural resources at unsustainable rates. Energetic constraints are fundamental to ecology and evolution, and empirical relationships between species richness and estimates of available energy (i.e. resources) have led some to suggest that richness is energetically constrained (Hurlbert and Stegen, 2014). The evolution of human civilization suggests also that human energy demand is getting closer to the total appropriation of Net Primary Productivity related to photosynthesis (Brown et al., 2011). The increasing risk of regime shifts, which can be triggered by several different drivers individually or also in combination, consists of a breakdown of the social norm, sudden collapse of co-operation and an over-exploitation of resources. This broadly corresponds to a decline of E and to an increase of μN (i.e.: individual appropriation and use of energy resources) values within equation (1). An interesting parallel arises with food webs and increasing energy requirements, which are dependent on μN (Bellingeri and Bodini, 2013). The size of population, N, is also relevant. In fact, population growth rates generally depend on whether new individuals compete for the same energy or help to "generate" (or, better, extract) new energy (Makarieva et al., 2008; DeLong and Burger, 2015). These costs are mainly payed by the biota, which guarantees the permanence of environmental stability. A further factor of instability related to human consumptions is the Human Appropriation of Net Primary Production

(HANPP), which provides a useful measure of human intervention into the biosphere. Future biodiversity loss might derive from three interacting factors: energy withdrawal from ecosystems due to biomass harvest, habitat loss due to land-use change, and climate change (Powell and Lenton, 2013). The resulting withdrawal of energy from managed ecosystems has a large negative impact on biodiversity. It is important to remark that biodiversity protection is of major importance for several reasons. In fact, biodiversity impacts the functioning of ecosystems in several ways (Cardinale et al., 2012): (1) influence on the efficiency by which ecological communities capture biologically essential resources, produce biomass; (2) decomposing and recycling biologically essential nutrients; (3) increasing the stability of ecosystem functions through time; (4) impacting non-linearly and through saturation, such that change accelerates as biodiversity loss increases. Moreover, loss of diversity across trophic levels has the potential to influence ecosystem functions even more strongly than diversity loss within trophic levels. Finally, functional traits of organisms have large impacts on the magnitude of ecosystem functions, which give rise to a wide range of plausible impacts of extinction on ecosystem function. As discussed in the same paper, anyway, the interplay between biodiversity and biodiversity-related ecosystem services should be further investigated.

Summarizing the found evidences: (1) energy demand and use of availability impacts on the biota and on the stability of human SES; (2) the high-level of human energy demand is different from the one usually occurring in stable ecological communities. This fact constitutes a threat for human SESs stability; (3) the indirect price payed is crossing the planetary boundaries; (4) among the prices to pay, biodiversity (and also noodiversity) losses could constitute a major damage both for humans and for the natural biota; (5) a breakdown of stability, toward a regime shift or societal collapse, could be manifested as a combination of breakdown of the social norm, sudden collapse of co-operation and an over-exploitation of resources. All these facts are interrelated and display different effects on the hierarchical stability of human SES.

Solutions are necessary to reduce the risk of societal instability, avoid the depletion of biodiversity and preserve the natural biota and its function, while improving human well-being. A mix of technical, economic, political and social solutions are required for such a purpose. It would be presumptuous to think that on-the-shelf solutions could be possible without further analyses. In fact, the complex interplay among different factors in societal stability is a well-known fact. It is also known that feedbacks and non-linarites might appear in different ways, as answers to different inputs. This is why this sub-section provides an approach for thinking about the multidimensionality of the possible roadmaps, more than simple recipes.

The energy hierarchy of human SESs might have appeared and evolved as a result of adaptive solutions to emerging problems, as remarked by Tainter (1998). This multi-level structuration requires an energy input, represented by availability. The possible pools are, broadly, lower level of the same structure or the biota. In simple words, availability is constituted by four terms: E, which is the energy that keeps the structure together; pV, which is work; μN, which is the individual energy accumulation of N individuals, that constitute the sub-system under study (microstate); TS, which is associated to dissipation. Three main consequences are derived: (1) We have to preserve the natural availability; (2) We should avoid the factors, which increase the human SES instabilities; (3) At the global level, the correlation between increased wealth and increased energy consumption is very strong and the impact of policies to reduce energy demand is both limited and contested. Nonetheless this issue should be included in the future action plans.

4. Conclusions

The paper, which assesses the basic thermodynamic properties of a human Socio-Ecological System (SES), analysed the civilization societal evolution and vulnerabilities, given its main energy features. There is evidence that the costs for maintaining the energy structure of a human SES are payed by the lower levels (i.e.: the components) of the society and by the biota (i.e.: flora, fauna and the environment). In particular, the increasing level of energy demand is forcing human SESs to move toward undesirable tipping points, which are well described within the planetary boundary framework. In order to avoid such an unwished transition, a multi-dimensional approach should be adopted. The redistribution of energy demand, the economic implications, the preservation of the natural biota and of biodiversity should be focal points for developing and adopting future policy roadmaps. Further investigations are also necessary, in order to better understand the energy dynamics associated to human SES structure for reducing the potential risk of a future societal collapse.

While a general description of energy-related properties for human societies at different levels is assessed, it is still difficult to define a general equation for describing its dynamics, due to the high number of terms involved. Among them, feedbacks and non-linearity should be accounted. Another point. Energy pressures on the environment must be determined at different spatial scales. This is already possible, using different indicators, such as energy footprint (e.g.: Fang et al., 2014; Jones et al., 2015; Lan et al., 2016). Moreover, integrating the data derived from human SES energy structure and its footprint, a better planning tool would become available for policy-makers and public managers. Such an instrument would become very useful, starting from the city level, considering the continuous growth of urban population around the world. Finally, as previously remarked, the influence of human SESs on the natural biota and the preservation of biodiversity are crucial for guaranteeing the preservation of life on our planet. Thus, the interaction among human and non-human energy hierarchies should be better understood and integrated.

Bibliography

Due to space constraints, the references, reported along the text, cannot be listed here. Consequently, reference list can be required directly to the corresponding author.

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Revisiting Terrestrial transport modalities in China: a survey of monetary, energy and environmental costs

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Abstract: The terrestrial transport sector delivers more than 85% of passengers and commodities in China, due to the large size of the country and its web-like economy, with huge exchange of resources among different provinces. The transport sector operations mainly rely on the support of infrastructure, vehicles, energy and labor. Former studies mainly focused on the energy consumption or emissions of the transport sector, which only displays part of the picture. In this paper we expand the scope of the investigation, by pointing out the amount, the quality and the distribution of resource use among the different transportation modalities at the level of the entire country. Three different assessment methods are compared, monetary, energy and emergy assessments. We found that the private car accounts for the largest share of the total cost of China terrestrial transportation and has much higher unit cost from monetary, cumulative energy and emergy points of view, which indicates the need to encourage the population to shift to public transport modalities characterized by much better performances. In fact, the unit operative costs of the private car are generally higher than any other modality, in so showing the lowest input-output and environmental efficiency. As a consequence, improvement of energy and environmental efficiency in individual transport modalities remains a priority. The ranking of most efficient transport modalities depends, as expected, on the evaluation method applied. From a monetary perspective, the most efficient passenger transport modalities are the regular train followed by the high-speed train. In terms of cumulative energy demand, regular train and subway have the lowest unit cost among all passenger transport modes. When it comes to the emergy (environmental support demand), the urban bus for passengers and the regular train for commodity transport show the best performance per unit service. Promotion of above modalities according to different purposes could improve the global efficiency and offer better and larger transport options with the same resource investment.

Keywords: transport efficiency; emergy; cumulative energy demand; monetary cost

1. Introduction

The transport sector in China is rapidly growing with the economics development. Specifically, the volume of the freight transport increased from 4445.2 billion ton-km in 2000 to about 17377.1 billion ton-km in 2012 and that of the passenger transport rose from 587.8 to 3338.3 billion passenger-km over the same period. The average annual growth rate was 22% and 36% for freight and passenger transport, respectively. In 2012, 84.71% and 52.89% of the total transport volume of the passenger and freight transport were delivered by the terrestrial transport because of the vast inner land area of China and relatively limited possibilities for sea transport implementation. Hence, a comprehensive and proper understanding of the terrestrial transport could be a prerequisite for the policy making and sustainable development of the transport sector.

Concerning the literature focusing on the transport sector in China, most existing studies only offer a partial picture. To be more specifically, (Liu et al., 2015) explore the energy consumption and CO_2 emissions by the passenger transport in Beijing. (Xu and Lin, 2015a) examine the carbon dioxide emission reduction of China's freight transport via vector autoregression model. (Hao et al., 2015) estimate and predict the energy consumption and greenhouse emissions by the Chinese freight transport through the year 2050. (Li et al., 2016) assess the impact of the integrated transport system in China as a function of monetary investment. (Xu and Lin, 2015b) identify the nonlinear relationship between the influential factors (per capita GDP, energy intensity, urbanization level, cargo turnover and private vehicle inventory) of the carbon dioxide emissions of Chinese transport. (Duan et al., 2015) quantify the carbon emissions of the transport sector in China by means of a streamlined life cycle assessment. (Gambhir et al., 2015) evaluate the technologies and the cost of the potential reduction of carbon dioxide in the Chinese road transport sector. (Ling-Yun and Qiu, 2016) estimate the relationship between the transport harmful emissions, the environment and human health in China. (Guo et al., 2014) identify the transport carbon dioxide emission patterns at regional level in China. (Peng et al., 2015) uncover the energy saving and emission reduction potential of the passenger transport in Tianjin. It is evident that most of the research results about Chinese transport sector pay large attention to emissions and energy consumption, while other indirect aspects such as quality and environmental cost of resource use as well as labor intensiveness and monetary costs are not sufficiently addressed. Of course, focusing on energy is of paramount importance for the transport sector. However, infrastructure, vehicles and drivers are also important factors to operate the transport sector and all these factors should be involved into the evaluation of the resource demand and sustainability of the transport sector.

We investigate the energy, monetary and environmental costs in support to the terrestrial transport sector in china. In order to do so, we have categorized the terrestrial transport sector into 9 modalities, namely private car, taxi, urban bus, long distance bus, subway, regular train for passengers, high-speed trains, trucks and regular trains for freight transport. Monetary assessment involves total cost investment for infrastructure, vehicles, energy and labor, while energy evaluation considers the direct and indirect commercial energy consumption associated with the construction of the infrastructure and vehicles as well as the energy used to drive vehicles. Furthermore, we also implement the emergy accounting approach, which considers the direct and indirect environment support to the production and operation processes related with the transport sector at the larger scale of the biosphere. These three evaluations focus on different characteristics of the transport sector (e.g., expensive technology, energy and labor intensity, need for infrastructures, resource replacement time) and could be used for different purpose oriented policy making. Expected results are both to ascertain the monetary, energy and environmental costs per unit of transport service provided and the total costs of each modality at the level of the entire country. Moreover, the most demanding and expensive input flows are investigated, in order to suggest targeted improvements.

2. Methods

This paper compares the terrestrial transport modalities in China in terms of monetary cost and energy depletion as well as of demand for environmental support in 2012, per unit of passengers and freight transported.

2.1 The terrestrial transport system in China

The terrestrial transport system is mainly composed by the road system, subway and railway systems. For the road system, we categorized it into different sub-modalities according to the transport purposes, namely private cars, taxi, urban buses and long distance buses, for passengers, and trucks for freight. Subway is a special sub-category, in that it only serves urban passengers as an alternative to road transport. Regular trains (electric and diesel) serve both passenger and freight transport, while high-speed trains are mainly used for passengers. Each transportation modality includes three main steps:

a) Construction and maintenance of infrastructures (road, railway, bridge and tunnels);

b) Construction of vehicles (cars, urban buses, long distance buses, subway trains, regular and high speed trains, trucks);

c) Operation phase (annual flows of energy, labor and services).

The basic data set of all modalities were collected from the statistic yearbooks, from published official government reports and from studies carried out by international Institutions, such as the World Bank. It is quite obvious that the road system takes the dominant role in the terrestrial transportation sector in terms of the length of the infrastructure and the service supported. The total length of the road system in China is 4.24E+06 km; in the railway system, the regular railway is 9.67E+05 km and the high-speed railway is 1.01E+04 km. The road system transported 5.76E+12 P-km in 2012 that accounts for 84% of total transport service by all terrestrial transport modalities, while the railway and subway systems transport 14% and 2% of the total transport service, respectively. Among the road transport modalities, private cars and long distance buses are the two most important ones and respectively provide a transport service around 3.01E+12 p-km (44% of the total) and 1.85E+12 p-km (27% to the total).

Table 1. The infrastructure, vehicles and services supporting the terrestrial transportation (2012)

Item		Amount	Unit
Infrastructure			
Road system			
	Extra urban road		
	Length	4.24E+09	m
	Area	3.69E+10	m^2
	Internal urban road		
	Length	3.11E+06	m

Area	7.50E+10	m^2
Train system		
Regular railway	9.67E+08	m
High-speed railway	1.01E+07	m
Subway		
Railway	2.06E+06	m
Vehicles		
Road system		
Private cars (No.)	8.84E+07	
Urban buses (No.)	4.19E+05	
Taxi (No.)	1.03E+06	
Long distance buses (No.)	8.67E+05	
Trucks (No.)	1.25E+07	
Train system		
Regular train (for passengers)		
Coaches (No.)	5.58E+04	
Locomotives (No.)	3.25E+03	
Regular train (for freight)		
Coaches (No.)	6.64E+05	
Locomotives (No.)	1.64E+04	
High-speed train (No.)	1.05E+03	
Subway		
Trains (No.)	1.26E+04	
Transportation service provided		
Road system		
Private cars	3.01E+12	p-km
Urban buses	7.01E+11	p-km
Taxi	2.10E+11	p-km
Long distance buses	1.85E+12	p-km
Trucks	5.95E+12	ton-km
Train system		
Regular train (passenger)	5.35E+11	p-km
Regular train (freight)	2.69E+12	ton-km
High-speed train	4.43E+11	p-km
Subway trains	1.15E+11	P-km

2.1 Accounting methods

We treated each transport modality as an independent system (disregarding, as comparatively negligible, the specific infrastructures that connect each modality to the others) and firstly carried out a thorough inventory of all the input flows on the local scale (foreground data). It is important to underline that this inventory forms the common basis for all subsequent assessments, namely monetary cost accounting, gross energy requirement and emergy accounting, which are carried out in parallel, thus ensuring the maximum consistency of the input data and inherent assumptions.

The raw amounts of input flows from the inventory phase are multiplied by suitable conversion coefficients specific of each method applied, which express the "intensity" of the flow, i.e. quantify to what extent a monetary, energy, or environmental cost is directly or indirectly associated to background flows over its whole life cycle. Such coefficients are available in published statistic yearbooks, energy and environmental accounting literature (emergy, LCA). In so doing, the background monetary, energy, and environmental "costs" associated to each flow as well as to the entire process are calculated, according to the following generic equation:

$$C = \sum C_i = \sum f_i \times c_i \quad i = 1,\cdots,n, \tag{1}$$

where C = monetary, energy or environmental cost associated to the investigated process; C_i = monetary, energy or environmental cost associated to the i-th inflow of matter or energy; f_i = raw amount of the -ith flow of matter or energy; c_i = moneraty, energy or environmental unit cost coefficient of the i-th flow (from literature or calculated in this work).

In order to carry out a reliable comparison of the different modalities, we referred all costs and impacts to one person or 1 tonne of commodity transported over one km, i.e. to functional units typical of transportation systems. The choice of such a functional unit seems the only one that allows a fair comparison of so different transportation modalities by means of so different evaluation methods. In so doing, the comparison can be drawn independently on the distance as well as on the actual volume of people transported. We therefore calculated the average demand for resources and environmental support related to such p-km and t-km functional units. By means of a whole-system approach, we were able to calculate and compare the monetary and energy depletion required as well as the environmental impact generated per functional unit of each analysed transport system, taking into account all the system's steps and components, not just the specific performance of individual vehicles, out of their operational context.

3. Results

Tables 3-5 provide monetary, energy and emergy values of input flows supporting selected investigated modalities. Due to the limit space we just display the evaluation results for private cars, regular trains and high-speed trains for passenger transport. The evaluation for other modalities could be found in the Appendix.

3.1 Monetary results.

Concerning the unit monetary cost (cost of p-km or ton-km), the taxi and private car rank in the topping places among all 9 modalities and cost 0.85Yuan/p-km and 0.79 Yuan/p-km, respectively (see table 1 and Appendix table A1). Meanwhile, the lowest unit cost is achieve by the regular trains (0.04 Yuan/p-km) and the high-speed train (0.07 Yuan/p-km) for passengers, The unit cost of the private car and taxi are double of that of trucks and even greater than other modalities, which means the same amount of the monetary investment in different modalities will offer different volume of services. For instance, the service offered by each modality could be various with the same amount investment. Specifically, the private car and regular train will offer 126.8 p-km and 2500 p-km with 100 Yuan investment, respectively.

To increase the efficiency from the point of view of monetary cost, road construction technology improvement is needed, capable to expand the life span of the road.

Table 2. Monetary evaluation of private cars, regular train and high-speed trains (passengers) transport in China (2012).

Note	Item		Amount			Unit/yr
			Private car	Regular train	High-speed train	
1	Oil derived fuels		6.03E+11	3.79E+09		Yuan
	1a	Without tax	3.24E+11	2.04E+09		Yuan
	1b	Tax	2.78E+11	1.75E+09		Yuan
2	Natural gas/electricity		5.07E+09	2.15E+09	7.67E+09	Yuan
	2a	Without tax	4.10E+09	1.78E+09	6.36E+09	Yuan
	2b	Tax	9.62E+08	3.65E+08	1.30E+09	Yuan
3	Infrastructure		1.03E+12	1.19E+10	1.19E+10	Yuan
4	Vehicles		1.33E+11	1.31E+09	6.72E+09	Yuan
		Without tax	9.94E+10			Yuan
		Tax	3.31E+10			Yuan

5	Drivers labor	5.97E+11	1.64E+09	6.65E+09	Yuan
	Total with tax	2.36E+12	1.91E+10	3.30E+10	Yuan
	Total without tax	2.05E+12	1.67E+10	3.17E+10	Yuan
	Total transportation service provided	3.01E+12	5.35E+11	4.43E+11	P-km
	Cost of unit of service with tax	0.79	0.04	0.07	Yuan/p-km
	Cost of unit of service without tax	0.68	0.03	0.07	Yuan/p-km
	Percentage of each modality of the total monetary cost	40.87	0.33	0.57	%

3.2 Energy results.

Private cars and trucks consume 66% of total 1.24E+13 MJ cumulative energy of all modalities, which means that these two modalities play a dominant role in the energy depletion and must be monitored for much needed improvement. The cumulative energy consumption structure is not the same for all modalities and could be categorized into two groups. The first group including regular trains for passengers and freight of which the cumulative energy of the supporting infrastructure is around 65% and 76%, respectively. In the second group (including all the remaining modalities), the largest fraction of the total cumulative energy consumption is the fuel and electricity used to drive vehicles and accounts between 74% to 84% of the total.

Come to the cumulative energy consumption per service, taxi and the private car consume 2.06E+10 Mj and 1.74 E+10 Mj to transport 1 p-km, respectively and are much higher than other modalities. The cumulative energy consumption of taxi is higher than the private car is mainly due to that the taxi offers less service than the private car. Hence, an easier approach to improve the energy efficiency for the taxi modality is to shift the private car drivers and passengers to the taxi. In contrast, subway and the high speed train just cost 0.21 E+10 Mj and 0.47 E+10 Mj direct and indirect energy to offer one unit of service, which means that the subway and high speed trains are the most efficient modalities among all terrestrial modalities and they could offer more service with given energy consumption.

Table 3. Cumulative Energy Demand evaluation of private car, regular train and high-speed train (passenger) transport in China (2012).

	Raw Amount	Energy (E+10 MJ/yr)

Note	Item	Private car	Regular train (Passengers)	High-speed train	Unit/yr	Energy intensity (MJ/unit)[1]	Private car	Regular train (Passengers)	High-speed train
FUELS									
1	Oil derived fuel	8.11E+13	5.80E+11		g	5.40E-02	4.38E+02	3.13E+00	
2	Natural gas	1.44E+12			g	1.20E-01	1.73E+01		
3	Electricity		3.58E+09	1.28E+10	kwh	1.50E+01		5.37E+00	1.92E+01
VEHICLES									
3	Vehicles	7.64E+12	2.16E+11	2.78E+13	g	6.93E-02	5.29E+01	4.70E+00	2.34E-01
4	Locomotives		2.12E+11					2.11E+00	
INFRASTRUCTURE									
4	Road/Railway	1.14E+15	9.38E+13	1.20E+12		1.20E-04	1.38E+01	2.41E+01	1.23E+00
Total transportation service provided		3.01E+12	5.35E+11	4.43E+11	P-km				
Total energy		5.22E+02	3.74E+01	2.06E+01	MJ				
Cumulative energy per service		1.74	0.70	0.47	MJ/p-km				

3.3 Emergy results.

Table 4 displays the emergy evaluation results of the private car, regular train and high-speed train (other modalities in the Appendix). The total emergy with labor and service used by the terrestrial transport modality is 6.42E+24 sej/yr, of which private cars and trucks account 72% (36% for each). For the dominant modalities of private cars and trucks, the emergy of the labor and service reach 77% and 79%, which means that these two modalities are labor intensive. Therefore, the development of the trucks transport could offer more jobs; the labor and time used by driving private car actually do not be paid and if transport these private drivers could save more time to relax and work. We also consider the total emergy without the labor and service that could display the demand of the natural resource of the transport sector. The total emergy without the labor and service of all modalities is 1.82E+24 sej/yr. The private car and the truck are still the dominant modalities and account 29% and 26%.

The emergy used by per service reflect the efficiency of using the resource and labor of each modality, the private car and taxi has the highest UEV per service among all passenger transport modalities and reach 7.65E+11 sej/p-km and 7.47E+11 sej/p-km, respectively. For the commodity transport, the trucks modality need 3.36E+11 sej/ton-km and is at least twice higher than the regular train.

1 The energy density of the vehicles and infrastructure is materials, weighted average energy density

Table 4. Emergy evaluation of private car, regular train and high-speed train (passenger) transport in China (2012).

Note	Item	Raw Amount			Unit/yr	UEV (sej/unit) (*)	Solar Emergy (E18 sej/yr)		
		Private car	Regular train	High-speed train			Private car	Regular train	High-speed train
RENEWABLE RESOURCES:									
1	Sunlight	2.43E+20	8.29E+20	5.22E+16	J	1	2.43E+02	8.29E+02	5.22E+01
2	Rain	8.04E+14	2.74E+15	1.73E+11	J	2.13E+04	1.71E+01	5.84E+01	3.68E+00
3	Wind	5.42E+17	1.85E+18	1.17E+14	J	1.00E+03	5.42E+02	1.85E+03	1.17E+02
4	Geothermal heat	1.34E+17	4.57E+17	2.88E+13	J	4.90E+03	6.56E+02	2.24E+03	1.41E+02
FUELS									
5	Oil derived fuel used by private cars	3.65E+18	2.67E+14		J	1.32E+05	4.82E+05	5.79E+09	
6	Natural gas used by private cars	2.01E+17			J	1.40E+05			
7	Electricity		1.29E+17	4.60E+17	J		2.82E+04	3.54E+05	1.63E+08
VEHICLES									
7	Vehicle	7.64E+12	2.16E+11	2.78E+10	g	1.92E+09	1.47E+04	2.41E+03	38.39E+04
8	Locomotives		6.27E+09		g			1.68E+02	
INFRASTRUCTURE									
9	Roads system	1.14E+15	1.38E+05	1.19E+12	g		3.24E+03	5.79E+09	21.83E+03
LABOUR & SERVICE									
10	Services for oil derived fuels	6.03E+11	3.79E+09		Yuan	8.61E+11	5.19E+05	3.27E+03	
10a	without tax	3.24E+11	2.04E+09		Yuan	8.61E+11	2.79E+05	1.76E+03	
10b	tax	2.78E+11	1.75E+09		Yuan	8.61E+11	2.40E+05	1.51E+03	
11	Services for natural gas/electricity	5.07E+09	2.15E+09	7.67E+09	Yuan	8.61E+11	4.36E+03	1.85E+03	6.60E+03
11a	without tax	4.10E+09	1.78E+09	6.36E+09	Yuan	8.61E+11	3.53E+03	1.54E+03	5.48E+03
11b	tax	9.62E+08	3.65E+08	1.30E+09	Yuan	8.61E+11	8.29E+02	3.14E+02	1.12E+03
11	Services for roads	1.03E+12	1.19E+10	1.19E+10	Yuan	8.61E+11	8.83E+05	1.03E+04	1.03E+04
12	Services for vehicle	1.33E+11	1.31E+09	6.72E+09	Yuan	8.61E+11	1.14E+05	1.13E+03	5.79E+03
	without tax	9.94E+10			Yuan	8.61E+11	8.56E+04		
	tax	3.31E+10			YUAN	8.61E+11	2.85E+04		
13	Drivers labor	1.12E+07	3.08E+04	1.25E+05	person-yr	2.21E+16	2.47E+05	6.80E+02	2.75E+03
Total transportation service provided		3.01E+12	5.35E+11	4.43E+11	p-km				
Total emergy (with L&S)							2.30E+06	3.47E+05	1.63E+08
Total emergy (without L&S)							5.30E+05	3.30E+05	1.63E+08
Total emergy (without tax)							2.03E+06	3.42E+05	1.63E+08
UEV of transportation service (sej/p-km), with L&S							7.65E+11	6.48E+11	3.68E+11

UEV of transportation service (sej/p-km), without L&S	1.76E+11	6.16E+11	3.68E+11
UEV of transportation service (sej/p-km), without labor of drivers	6.82E+11	6.47E+11	3.68E+11
UEV of transportation service (sej/p-km), without tax	6.75E+11	6.39E+11	3.68E+11

5. Conclusions

Previous studies about the transport sector in China only mainly focus on the regional greenhouse emissions or single transportation type (passenger or freight), which is difficult to display in a comprehensive picture. Thus, we implemented the monetary, energy and emergy evaluations of the terrestrial passenger and freight transport in China in the year 2012 in order to achieve a deeper understanding of the Chinese transport sector at the national level.

Monetary and energy evaluations display a specific aspect of the transport sector, while emergy accounting involve the social and environmental perspective compact. The evaluation results and ranking of the modalities are different for different methods. The monetary and energy results are more similar, which means the policy try to lower the economical cost also could improve the energy efficiency. The emergy results prove that the transport sector operation need more than energy, vehicles and infrastructure. Labor and service are also necessary components for transport. Specifically, the labor intensive feature of public transportation will help to create more jobs, while limitation of private car could save more time for the driver to more productive activities. Thus, it is important to choose propitiate evaluation method due to the purpose.

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An Analysis of Energy Poverty in Romania

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Abstract

Reducing poverty and increasing energy access for the poor have been a priority for institutions such as the World Bank and United Nations. Residential energy poverty can be defined as a condition where households cannot afford energy to a necessary level for homes. Eastern Europe is not often considered in this context. Public policy regarding energy supply in Europe, especially Eastern Europe, has many ramifications as international relations with Russia, one of the main suppliers of energy to Eastern Europe, worsen. However, since the end of Communist regimes, there have been many energy, housing, economic, and social reforms that have had implications for energy poverty. In particular, the liberalization of energy markets in Eastern Europe have led to energy poverty. For example, high energy prices, poor building insulation, and lack of access in certain parts of Romania combined with income poverty have created energy poverty for many Romanians. This paper provides an examination of energy poverty in Romania. Empirical data is offered to connect household energy poverty to the type of household.

1. Introduction

Energy poverty is one of the biggest issues facing the world today and a priority for institutions such as the World Bank and the United Nations. "Eradicating poverty is the greatest global challenge facing the world today and an indispensable requirement for sustainable development, particularly for developing countries … This would include actions at all levels to: (provide)… The access of the poor to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services (World Summit for sustainable development, Johannesburg, 4 September 2002). Energy poverty is defined in this paper as *a condition where an individual or a household are not able to afford to adequately meet their required energy needs*. There is an expanding body of evidence suggesting that energy poverty is an escalating problem in Eastern Europe, due to the specific social and physical conditions that exist there, such as cold climates, the liberalization of energy prices, and the reliance on foreign sources for their energy supplies, for example, Russia (Lampietti and Meyer, 2003; Buzar, 2007). Furthermore, income in many of these countries, especially Romania, have been flat or decreasing up until mid-2016. Due to this stagnant income and increasing energy prices, many households had no option other than to reduce their energy purchases.

The former socialist countries in Eastern Europe were known to place a major emphasis on energy security and developing new sources for supply (Gray, 1995). As a result, Eastern European economies became excessive energy consumers, heavily reliant on carbon-based fuels; an energy intensity problem - a low value on energy and other natural resources leading to their overconsumption (Gray, 1995). Further exasperating the problem, the centrally-planned economies treated housing and heating as goods and services which were meant to be accessible for all. Therefore, housing, public transportation fees, and energy were heavily subsidized

(Duke and Grime, 1997). Consequently, consumers had no relationship with the true cost of energy. In fact, consumers were given misleading information about the costs which led to the misallocation of resources (McAuley, 1991).

Making matters worse, the vast majority of urban households in the communist Eastern European countries had direct heating. According to Buzar (2007) the centrally located combined heat and power or heat only boiler plants typically burn coal or fuel oil in order to produce hot water usually for space heating and direct household use. The hot water was transported through pipelines to substations where it was distributed to collective or individual buildings. The direct heating pipes and apartment buildings were vertical requiring radiators in rooms that were on top of each other to be supplied by the same pipe. Therefore, radiators in different rooms were connected to different types making it very difficult to measure energy consumption at the household level, especially since meters were often not used. As a result, room temperatures were often too low or too high, causing windows to be open to cool over heated rooms leading to losses of heat. Internal and external corrosion of pipes and lack of adequate insulation or any insulation at all contributed to additional efficiency problems. Additionally, although direct heating required high population densities to justify its high capital costs, many of the former communist Eastern European countries constructed direct heating infrastructure in small towns and villages.

With the end of communism, the subsidies that existed for energy costs were put under pressure to be removed. As a result, the privatization or partial privatization of the energy industry in these countries slowly occurred. The idea was that consumers would pay the full economic cost of production, distribution and supply of electricity they consume (Stern and Davis, 1998). However, direct heating systems remained. Consumers, already complaining that energy costs are too high, have resisted the reduction in subsidies.

In Romania, direct heating systems still exist in many apartment blocks and, while subsidies have decreased, they still exist. Here, an individual or household having to reduce their energy consumption is troublesome as many of these individuals or households are likely to be pensioners, unemployed, or low income. In times of extreme heat or cold, this reduction in energy consumption could be life-threatening. Moreover, as the Romanian economy is still developing, the government has not yet been able to develop suitable social safety nets to protect these energy poor individuals or households. The problem is even more complex because of the connection between social, energy, and housing reforms that have taken place in Romania since becoming a EU member state (January 1st, 2007).

The vulnerable populations include those with little marketable skills and less mobility, such as children, the elderly, women, the disabled, some minority groups, and single parents (Torrey et al., 1999; Cornia et al., 1996). However, there are other groups that are just as much at risk. For example, young adults who may have just graduated and are looking for employment, the long-term unemployed, subsistence or semi-subsistence farmers, and those that live paycheck to paycheck. This last group, considered the working poor, do not necessarily fit the definition of the economic poor. These people could have well-paying jobs but may not have the disposable income after paying for their necessities to afford the energy consumption they need. For example, a single parent that is employed in considered middle-class may not have enough disposable income for the required energy consumption after paying for child care, food, transportation, and shelter. Romania does not have the national income necessary to provide social assistance benefits to the households that need.

Unlike income poverty which can be defined as having a lack of financial resources, energy poverty is much more intricate. Energy poverty can be related to poverty, but does not have to be. Energy poverty can be related to domestic energy efficiency but does not have to be. Energy poverty can be related to political circumstances but does not have to be. As a result, energy poverty is very difficult to define due to its complexity. In developing countries, the search for energy is a continuous battle (Sovacool, 2014). However, those in developed countries are not immune to the problem of energy poverty either.

This paper examines the issue of energy poverty for Romania after joining the EU (2007 to 2015). In the 10 to 15 years following the Revolution in Romania, unemployment soared, income inequality grew, and few economic and social indicators remained unaffected (Fajth, 1999: 417). The last decade or so, has seen a stabilization of economic and social indicators in Romania resulting in economic growth. However, energy poverty persists. The next section briefly explores the literature on energy poverty. Section 3 describes the data and provide the results. Section 4 concludes the paper.

2. Review of literature

Revelle (1976), Krugman and Goldemberg (1983), and Goldemberg et al. (1985, 1987) were among the first to examine energy poverty. In particular they sought to estimate basic energy needs. Pasternak (2000) showed that there is a strong relationship between human well-being and consumption of energy and electricity. A positive correlation between the human development index (HDI) and annual per capita electricity consumption for 60 countries accounting for 90% of the world's population was found. He also found that HDI is maximized when electricity consumption is about 4000 kWh per person per year.

Pachauri et al. (2004) then examined different approaches for measuring energy poverty by using Indian household level data. They found a positive relationship between well-being and consumption of clean and efficient energy. Catherine et al. (2007) explored the efforts by the UK government to eradicate fuel poverty among vulnerable families by 2010 and for common people by 2016 using the Family Expenditure Survey. They looked at the characteristics of households in each group and the interconnectedness with different household issues. Barnes et al. (2010) examined energy poverty in Bangladesh by exploring the welfare impacts of household energy use in rural areas. They found that 58% of households in rural Bangladesh are in energy poverty.

3. Data and Results

The data used for analysis comes from the National Institute of Statistics Romania. Included in the data are prices for electricity and natural gas, energy consumption by fuel type, population statistics, and socio-economic data. Furthermore, data such as households at risk of poverty, income inequality, and caloric intake were obtained. Lastly, information and statistics on the percentage of households that can afford to maintain a proper temperature and the percentage of households that could not pay their electrical and radio bills on time were also in the data set.

The average monthly income, savings, and expenditure share in income for Romanians are shown in Figures 1-3. This data is important in regards to energy poverty because it shows the disposable income that is available to Romanians and whether or not they have an adequate private safety-net to pay for any unforeseen expenses or emergencies. Furthermore, this will help illustrate whether or not a public safety-net is necessary for the Romanian government to create to ensure that people do not suffer from inadequate consumption of energy.

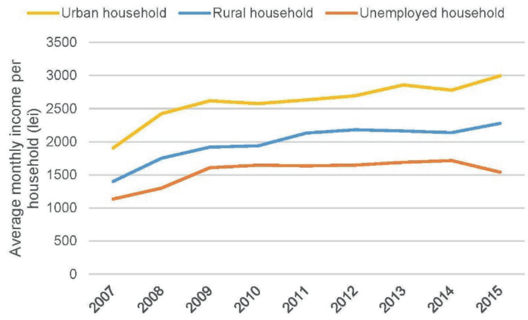

Figure 1: Average monthly income per household (lei)

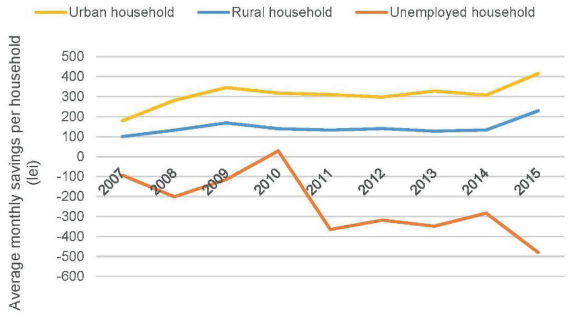

Figure 2: Average monthly savings per household (lei)

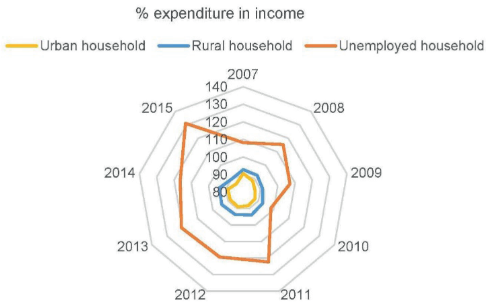

Figure 3: Share of expenditure in income (%)

Figure 4 illustrates the percentage of households that cannot pay their electrical bill on time. While by itself it is not a one hundred percent reliable indicator of energy poverty, this data does provide a gauge as to how many people are vulnerable to energy poverty. Specifically, this information shows the percentage of households that may not be consuming as much energy as they wish to, one definition of energy poverty.

As one may expect, those that live in rural areas and those that are unemployed have the highest rates of inability to pay their electrical bills. The unemployed are unable to pay their electrical bills because they do not have a source of income. Those living in rural areas in Romania are very susceptible to energy poverty because many of those individuals are subsistence or semi-subsistence farmers. These individuals will be captured in the statistic as they would not have much or any disposable income to pay for their energy needs. However, there are two caveats to be careful about here. First, individuals in rural areas are very likely to supplement their energy consumption with energy sources that are off the grid. For example, they are likely to burn wood. Second, they are likely to be individuals that live in rural areas that are completely off the grid and who are not captured in the statistic and, therefore, are energy impoverished.

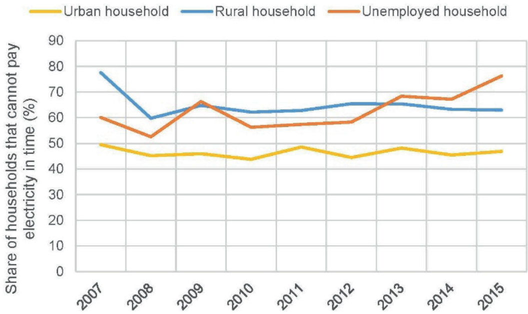

Figure 4: Share of households that cannot pay their electrical bill on time (%)

Figure 5 shows what percentage of households can keep the house warm in the cold season. The direst situation is for unemployed families. As shown, less than seventy percent of unemployed families can keep their household warm. This potentially has several implications. First, the lack of heat could cause health issues which can impact the welfare of the household since family members would not be able to work or go to school. Second, cold temperatures can impact the ability for any children in the household to do their schoolwork or concentrate on their studies. Lastly, the lack of heat could negatively impact the ability of household members to rest adequately, impacting their lives when they are not sleeping.

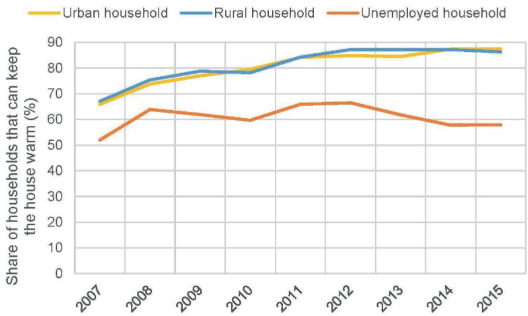

Figure 5: Share of households that can afford to keep an adequate temperature in the house (%)

One other indicator that should be considered for energy poverty that is not is daily caloric intake. While this may seem odd, the human body needs energy to function through metabolic processes, and that energy is obtained from caloric intake. This approach is more holistic, but we argue necessary because human energy is the cornerstone for well-being and economic production. Figure 6 shows the average daily caloric intake for Romanians.

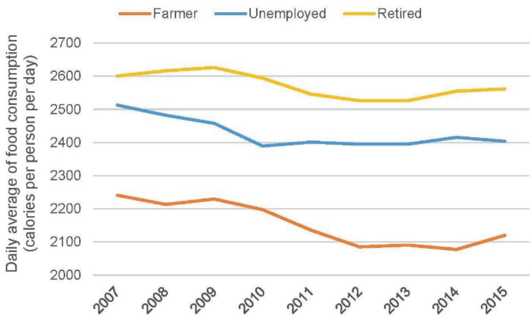

Figure 6: Average intake of calories from food per person per day

Depending upon which level daily caloric intake, either 2000 calories or 2500 calories, Romanians, in particular farmers, are either barely obtaining their minimum daily caloric intake, if using the 2000 calories level, or are below the minimum standard, if using the 2500 calories level.

4. Concluding comments

This paper examines energy poverty from a different perspective. There are many definitions of energy poverty as has been shown in this paper. However, we have chosen to take a more holistic approach including traditional indicators of energy poverty as well as a slightly more controversial indicator in daily caloric intake. Due to space restrictions, we were unable to discuss in detail many of the issues regarding energy poverty in Romania but have highlighted some of the more important statistics in regards to this issue in the country.

Energy poverty is a very important topic for many countries, especially developing countries such as Romania. Furthermore, the issue of energy poverty in Romania is of interest due to the liberalization of energy policies within the country making many citizens vulnerable. Therefore, this paper is important because it calls attention to the topic of energy poverty in a developing country going through liberalization policies, highlighting the necessity of safety-nets for economically vulnerable people.

Acknowledgement

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How Innovation and disruption is reshaping the future of the power sector

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Abstract

The electric power sector is undergoing fundamental transformations at an unprecedented pace brought about due to rapid uptake of distributed energy resources or DERs, a two-edged sword which is eroding utility revenues as increasing number of consumers become prosumers by using less – through energy efficiency schemes – while producing more of what they consume – through distributed self-generation. If the cost of storage declines, as expected, prosumers can move a step further by becoming prosumagers – consuming, producing and storing energy by better management of when and how energy is used, generated and/or stored. Moreover, promising developments in machine-to-machine (M2M) communications, open platforms using blockchain encryption allows prosumers to engage in peer-to-peer (P2P) trading by sharing distributed generation and storage. Add a new generation of aggregators, integrators and intermediaries will open new opportunities for consumers, prosumers and prosumagers to become proactive in future energy marketplace both at retail and wholesale level. This presentation examines how such developments are disrupting the traditional business model of the incumbents while creating opportunities for new entrants and the challenging facing the regulators and policymakers. The implications of developments in power sector are important since an increasing share of global primary energy is diverted to electricity generation.

By now the narrative on the rapid transformation of the electricity sector driven by the 3Ds – **decentralization, de-carbonization and digitization** – is well-known. Far less, however, is known about how this transformation is going to materialize, when and who may be the ultimate winners as the incumbent's traditional business models are disrupted. Not surprisingly, there are as many predictions on the end game as there are analysts and experts following the developments.

On the market: Solar tiles to cover exterior of buildings

Writing in a recently published book titled **Innovation & Disruption at the Grid's Edge, Sioshansi** makes the following rather obvious observation: "… innovation and disruption enabled by new technologies – notably **information & communication technology** (ITC) – are transforming the electric power sector at an unprecedented pace … allowing a growing number of previously passive **consumers** to become active ***prosumers***."

Prosumer, of course, refers to a consumer who is consuming part of the time and producing at other times, say a homeowner with rooftop solar panels. He adds, "These empowered prosumers … can reduce their dependence on the services traditionally delivered by the assets and infrastructure upstream of the meter by increasing their reliance on **distributed energy resources** (DERS), which by definition, are provided, consumed and possibly stored locally."

Prosumage: Stand-alone solar light generates & stores energy totally off-grid

Sioshansi, capturing the flavor of contributions of other scholars, experts and academics to this compendium, goes on to say: "Add a host of new intermediaries with sophisticated capabilities who can aggregate flexible loads and distributed generation – which can be effectively bid into wholesale markets – and one can see the power of aggregation enabled by **automated machine-to-machine** (M2M) communication. Advances in **artificial intelligence** (AI) are likely to lead to proliferation of services offered by such intermediaries who can provide valuable services to grid operators and distribution networks while better managing energy consumption and reducing participants' energy service costs."

He adds, "But innovation and disruptions don't end there. There is increased interest in **transactive energy** and **peer-to-peer** (P2P) trading facilitated by platforms that allow consumers, prosumers and prosumagers to better manage their consumption, distributed generation and storage, and not just internally but with their neighbors and among their peers. While many regulatory obstacles remain to be resolved, the distribution network physically connecting the participants is already in place."

"Bitcoin and **Blockchain technologies** – among others – offer new opportunities for such transactions to take place among and between consumers using the existing distribution network and related infrastructure."

"**Microgrids**, another promising emerging technology, offers individual customers and/or a collection of customers to better manage their consumption, distributed generation and storage, allowing them to operate independent of, or parallel to, the super-grid …"

Elon Musk & Patrick Pouyanne think alike: Integrated electricity services

The implications of such developments on the incumbents in the utility sector are beginning to be felt and speculated. But what has been experienced to date, say 5+ GW of distributed solar rooftop generation in California and even more in Australia, do not begin to count as even the tip of the iceberg compared to what may follow. As the consumer, to prosumer to prosumager scenario unfolds, as many expect, the definition of *electricity service* and – more important – how it is priced – will undoubtedly undergo radical transformation.

Viewed in this context, **bundled retail tariffs** – designed for the one-directional networks of the past century with passive consumers – which is still prevalent nearly everywhere in the world, is clearly outdated. **Volumetric tariffs** no longer capture the emerging **value proposition** offered by the grid – which offers connectivity, balancing services, frequency control, voltage stability and 24/7 reliability most coveted by increasingly sophisticated prosumers or prosumagers rather than delivering a large volume of kWhs. This suggests that the power sector is on a path not unlike that of **mobile phone industry**, where most users pay a fixed monthly fee based on a 2-year contract with a network service provider.

While the analogy is not perfect – e.g., currently electrons cannot be delivered without copper wires – it is clear that mobile phone service is increasingly about *connectivity* and *access* to the network rather than the volume or frequency of calls. Subscribers choose a provider on the basis of the ubiquity and reliability of its network access, the strength of the signal, bandwidth and speed. They are rarely charged on a per-call or per-minute basis. The cost of service is much better reflected, and collected, through a fixed fee almost regardless of the volume of service. The same goes for garbage collection and many other services where the fixed costs account for the overwhelming percentage of cost of service.

Integrate solar into the design from start, rather than as an "add-on" later on

Another reason why electricity service is moving in this direction is the fact that as the proportion of renewable generation on many networks increases, the cost of electrons – the commodity portion of service – is rapidly falling, eventually approaching zero, occasionally going negative. The kWhs are already relatively cheap and getting cheaper over time. Charging based on volume is outdated and will become unsustainable as a means of covering the cost of the delivery network.

Moreover, with the advent of **zero net energy** (ZNE) buildings, the volume of consumption in many places is flat or falling. The implication is rather clear: tariffs based exclusively or primarily on volumetric consumption are unlikely to deliver sufficient revenues, nor do they make much sense.

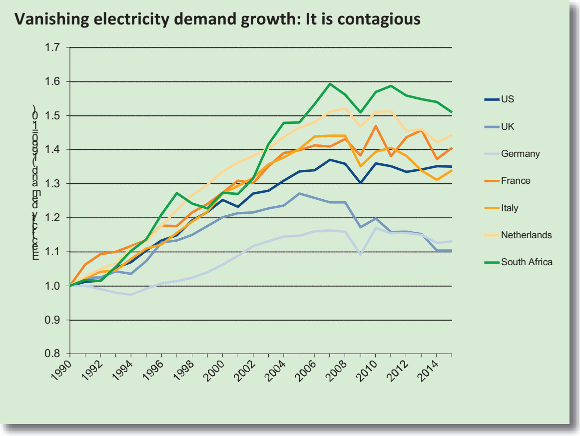
Moving towards the inevitable end, however, is not easy for a number of reasons:

- The path and pace forward looks different to different stakeholders who are often competing with conflicting views and perspectives;
- The incumbents don't like being disrupted and/or becoming irrelevant; and, most important
- The regulators, who control all aspects of the business in most markets, are having a difficult time following the rapid technological changes taking place, let along being in a position to lead or encourage innovation.

This is evident, for example, in the current piecemeal and fragmented treatment of **distributed energy resources** (DERs) and **net energy metering** (NEM) in various parts of the US. The *value* and/or the *cost* of DER resources, poorly understood, need to be better monetized and reflected in future tariffs, which must increasingly account for the bi-directional flows of electrons based on time, location and their value or impact to/on the distribution network.

Consider the following examples:

- A **solar rooftop panel** feeding a huge surplus – in excess of local consumption – to the distribution network on a cool, breezy, sunny day is not adding much value in a place like California, with its famous “Duck Curve;”
- By contrast, an **electric vehicle** or **distributed storage** device of any shape, form or size, taking unneeded excess electrons from the same circuit, and injecting it back after sunset, is providing a highly valuable service.



Vanishing electricity demand growth: It is contagious

Current tariffs and regulations, with a few exceptions, do not fully or even partially recognize, monetize, reward or penalize for the vastly different cost/value of such resources.

The good news is that regulators in states including **California, Hawaii** and **New York** – with the latter’s pioneering **reforming the energy vision** (REV) – are beginning to address how the changing role of the distribution network will redefine the role of stakeholders, including better clarity on who can do what, when and where and under what types of rules, rewards and investment recovery.

A number of such issues are covered in **Innovation & Disruption at the Grid's Edge**.

In the book's Preface, **Michael Picker**, the President of **California Public Utilities Commission** (CPUC), says he has "… chosen to focus actively at the CPUC on more tangible tasks that can deliver benefits quickly, rather than questioning the fundamental nature of utility business models," adding, "The **overarching** philosophy I have followed in pursuit of more distributed energy future can be described as '**Walk, Jog, Run**.'"

With so much on his plate, so to speak, the measured approach is understandable. Picker goes on to say, "The vision we (the CPUC) are pursuing is that, over time, DERs will be able to benefit from 'stacking' multiple value streams."

Future is distributed: Apple's new headquarter is zero net energy

Stacking, of course, refers to the fact that DERs, depending on when, where and how they feed or withdraw from the network, imply costs or value, often from multiple sources, as the examples of the solar PVs and EVs (above) described. In this context, stacking entails improved **monetization** of the multiple benefits of DERs while – paradoxically – acknowledging their increased demands on the distribution network – for example, with high concentrations of PVs and/or EVs on certain distribution circuits. California's regulators are already sensitized to the new realities of DERs and other innovations and disruptions taking place at the so-called ***grid's edge*** referring to the intersection of the distribution network and customers' meter and beyond- or behind-the-meter.

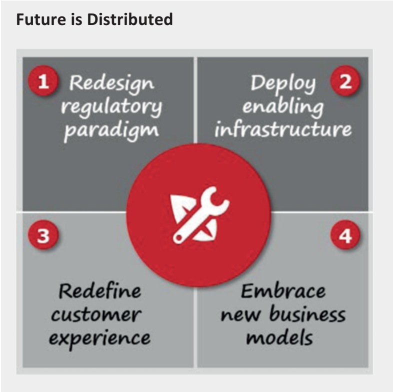
On this, Picker adds: "Targeting DERs to high-value locations also necessitates development of a tool to highlight areas of the distribution grid where DERs can provide location-specific values, such as distribution capacity deferral and voltage support.'

Likewise, in the book's **Introduction, Audrey Zibelman**, former Chair of the **New York Public Service Commission** and now the CEO of the **Australian Energy Market Operator** (AEMO), explains that: "The crux of the utility changes contemplated in REV (**reforming the energy vision**) can be summarized into the following 5 areas, many of which are touched upon by authors of the [book's] following chapters:"

- Creation of a **Distributed System Platform** (DSP);
- Promotion and encouragement of innovation;
- Regulation of the earnings model;
- System information and transactive markets; and,
- Fair and cost effective universal access.

Two other regulators, **Paula Conboy**, Chair of **Australian Energy Regulator** (AER) and **Johannes Mayer**, Head of Competition & Regulation at **E-Control Austria**, echo similar sentiments in the book's **Foreword** and **Epilogue,** offering perspectives from Australia and Austria, respectively.

The key question for the incumbents in the business, **retailers, distribution companies, generators** and **gentailers**, is how to survive – and hopefully thrive – the transition and the disruptions. That is the proverbial $64,000 question.



The Future of Electricity: New technologies Transforming the Grid Edge, a report by the **World Economic Forum** in collaboration with **Bain & Co.** released in March 2017, offers 4 broad recommendations for utilities, network operators and the regulators in moving forward:

- Redesign regulatory paradigm;
- Deploy enabling infrastructure;
- Redefine customer experience; and
- Embrace new business models.

The challenge is how to implement the sensible words into actionable strategies given the many moving parts and the complicated and highly unpredictable regulatory environment in which many utilities operate.

With so many moving parts, uncertainties, and pitfalls, it won't be easy.

Innovation and disruption at the gird's edge, published in May 2017 by **Academic Press**, is further described at the end of this newsletter including the Table of Contents. Copies may be ordered with 30% discount using **Code ENER317**, shipping included, at https://www.elsevier.com/books/innovation-and-disruption-at-the-grid-s-edge/sioshansi/978-0-12-811758-3?start_rank=1&producttype=books&sortby=sortByRelevance&q=sioshansi

The urban metabolism of Lima: perspectives and policy indications for GHG emission reductions

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In this paper we assess the urban metabolism of the metropolitan area of Lima, the largest urban agglomeration in Peru, which has recently surpassed 10 million inhabitants. This coastal megacity, located within the Rimac, Chillón and Lurin watersheds constitutes the socioeconomic center of the country and is the hub of the main import and export routes. We use the multi-layer approach proposed by Kennedy et al. (2014, 2015) to explore material and energy flows in the Peruvian capital for a 10 year timeframe.

Our results show that in 2006 the GDP of the 49 districts that shape the metropolitan area of Lima was 105.2 billion USD-PPP , while in 2014 it reached about 200 billion USD-PPP.

Based on this growth, we highlight that energy, electricity and water flows experienced a linear increase with respect to GDP, being the electricity consumption in years 2006, 2011 and 2014, 7295 GWh, 10,112 GWh, and 11,465 GWh, respectively. Regarding demographics, population growth ratios of GDP (650%), electricity consumption (400%), solid waste production (250%), and water (100%) confirm the results of superlinear scaling found by Kennedy et al (2015) for the other megacities.

Finally, we also compute the increase in greenhouse gas (GHG) emissions following an important shift in the primary energy sources to produce electricity. The most important change was linked to the shift from hydropower to natural gas, a trend that initiated in 2006. For instance, in 2001 79% of the total electricity production came from hydropower, whereas in 2014 69% was linked to natural gas. This shift produced an increase of GHG emissions of more than 200% in 2014 when compared to the electricity generation mix of 2001. Following these results, we strongly encourage policies for the decarbonization of the electricity production sector, as well as for mobility infrastructures, e.g. electric public and transport sector, with a progressive shift towards electric mobility.

On the Emergy accounting for the evaluation of road transport systems: an Italian case study

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Abstract

Road transportation is one of the most polluting as well as energy-intensive sectors, and requires planning policies capable to address at the same time several different environmental, social, and economic issues. Cost-benefit analyses are generally carried out with a major focus on fuelling and driving efficiency, whereas a systemic approach appears to be needed for a more comprehensive evaluation of the alternatives that may become available to address any issue, be it intended for either short-term or long-term spans. For instance, building up a new infrastructure might allow for savings in time or fuel per km, but this may require an equivalent or even higher socio-environmental investment. In this work, a short review is presented of some systemic studies on transportation that use the emergy synthesis methodology. A case study is also addressed, concerning recent important expansion works on the Apennine Mountains section of the Italian major highway A1. In particular, the analysis points out the role of time saving, since for a new or renewed transport infrastructure (and when comparing for example road to rail transport) saved time is likely to become crucial in justifying civil enterprises. Nevertheless, the present emergy synthesis and the teaching of H.T. Odum (Odum & Odum, 2001) warn us that such "luxury" highly depends on the abundance of available energy, which is less and less given for granted, whereas a systemic analysis approach may indicate different levels of criticality when oriented towards environmental and well-being issues.

1. Road transport: which approaches for a problematic sector?

The increasing energy demand and the polluting, climate change related emissions are widely considered among the main environmental issues for the XXI Century. In this framework, the transportation sector plays a primary role both in energy use and in pollutant emissions. In 2015, transports accounted for over 28% of the total energy use in the United States of America, and for the 70% of the country total petroleum consumption (equivalent to almost 15% of the world petroleum consumption in 2014), with more than 80% of the U.S. transportation energy use coming from highway vehicles (Davis *et al.*, 2016). In 2015, highway vehicles were responsible for the 39% of the total carbon monoxide (CO) emissions and for the 36% of the nitrogen oxides (NO_X) released in the U.S. (EPA, 2016). Although at a smaller scale, percentages in Italy appear even more dramatic: in 2014, over 39% of the national total energy use was related to the transportation sector (MISE, 2015), with on-road vehicles being responsible for the 23% of the total CO emissions and for the 50% of the total NO_X emissions (ISPRA, 2016). But whilst the problem is quite clearly addressed, the strategies for its overcoming are not. Facing transportation issues requires planning policies capable to address at the same time several different environmental, social, and economic aspects. Cost-benefit analyses[1] are generally carried out with a major focus on fuelling and driving efficiency, whereas a systemic approach and the

[1]https://www.fhwa.dot.gov/planning/processes/tools/toolbox/methodologies/costbenefit_overview.cfm

enlargement of the analytical boundaries appears to be needed [2] for a more comprehensive evaluation of the alternatives that may become available to address any issue, be it intended for either short-term or long-term spans. For instance, building up a new infrastructure might allow for savings in time or fuel per kilometre, but this may require an equivalent or even higher socio-environmental investment, which is hardly measurable by money – or at least quite indirectly. Emergy accounting (Odum, 1996) offers a great opportunity to account for environmental and labour/services costs and benefits at the same time, while addressing systemic interconnections and hierarchies. The limited available literature on emergy accounting applied to transportation has been reviewed, as described in Section 3. Emergy accounting is applied to an Italian case study, as illustrated in a forthcoming extended study (Cristiano, Gonella, & Ulgiati). Besides a short presentation of the state-of-the-art of the topic, this work discusses on how to frame the societal "value" and the socio-environmental "cost" of saved time in Odum and Odum's reasoning on a prosperous way down (2001) perspective.

2. Emergy accounting in a nutshell

In recent years, starting from the three pillars of sustainability (environmental, social and economic), the search for comprehensive integrated indicators of sustainability has been developing following various different approaches. What is needed to fully understand a system performance is an integrated approach capable to evaluate a process from two complementary points of view at the same time, namely, a "user-side" assessment that looks at final efficiency indicators (energy delivered per unit of energy input, emissions per unit of energy, and so on) along with a "donor-side" framework, that considers the work done by the supporting ecosystemic and social/productive environment in providing resources.

The term "EMERGY" is derived from the expression "EMbodied enERGY". The foundations of emergy analysis are the main scientific output of the work by Howard T. Odum (Odum, 1996; 2000; Odum & Brown, 2007). Starting in the 1970's, Odum structured and applied the emergy analysis over a surprisingly wide range of systems (see Brown & Ulgiati, 2004) within several disciplines, among which complexity science, ecology, economics, informatics, geo-bio-physics, sociology and so on. The emergy, defined as the available energy of one kind that is used up in transformations directly and indirectly to make a product or service (Odum 1996), may be regarded as a sort of "memory" of what has been invested, in terms of energy involved either directly or indirectly, to realise something. Emergy represents the common unit (defined along with a proper algebra) for accounting at the same time all the quantities, flows and processes that concur in defining the system at issue. The unit of emegy is the *solar emjoule*,in the case of solar energy reference. The emergy of a resource will include all the upstream and downstream contributions provided by both the environment and the anthropic activities necessary to maintain that resource. The emergy approach takes quantitatively into account within the same unit all the flows, namely, matter, energy, information and money, so putting into the same technical-scientific analysis also quantities not computable in terms of money or energy units, that are therefore typically neglected in economic or energetic analyses.

The general methodology for the emergy analysis of a system is typically organised in

[2] http://bca.transportationeconomics.org/published-guidance-and-references

the fundamental steps:

1. Build up of an emergetic diagram of the system;
2. Preparation of an inventory table for the flows;
3. Determination of the corresponding emergy values;
4. Calculation of suitable emergetic indicators for the analysis interpretation.

The elements of the emergy diagrams are mutuated from the formal and graphical language used by engineers for energy networks (Odum, 1996). Starting from the emergetic diagram, all data for the respective flows are converted in emergy units by means of their respective Unit Emergy Values (UEVs), which are given by the emergy required to generate an output unit, be it made of mass, energy, labour, money, and so on, independently of the renewability of inputs.

3. On the prosperous way down

The Prosperous Way Down outlined by the Odums frames a possible scenario for the future of the humanity, where the depletion of nonrenewable fossil energy sources may lead to a society living on fewer resources but at the same time that may be prosperous as well. To pursue this, human activities should follow an epistemological picture based on a donor-side perspective, like that substantiated by the emergy analysis, that may indicate in a scientific manner how to try modifying the economy and keeping the environment prosperous as resources become more and more limited. Odum pointed out several features of modern society that must undergo a profound change, among which the transport sector plays a role in as much it is related to several human activities of a global society that produces and consumes as much fossil fuels as possible, mostly for private interests strongly intertwined with global politics. Among the indications for a prosperous way down, some are of particular interest for the topic at issue (Odum & Odum, 2006), namely:

- Decrease in urban concentration, based on the fact that the concentration of economic enterprises and people in cities is ultimately based on the availability of inexpensive fuels.
- Re-shaping of the automobile culture, by reducing the number of cars as well as unnecessary horsepower.
- Communication replacing transportation, whenever an activity does not require physical displacement of matter.

All of these aspects require that the whole economy re-shapes its basic postulates concerning the use of fossil fuels, still allowed and promoted at the global level despite any environmental concern. In this sense, a bottom-up approach may regard the local level, and so the analysis presented in this contribution.

4. Emergy accounting and transportation

The literature reporting emergy accounting approaches for road transportation systems is quite limited. Roudebush (1996) focused on the comparison between the different costs and impacts of concrete versus asphalt road pavements; Brown & Vivas (2005) tangentially addressed transportation infrastructures while incorportating roads (specifically, their empower density) in the calculation of the Landscape Development Intensity index of a given territory; Reza *et al.* first used paved roads as a case study to investigate the uncertainties in emergy accounting (2013), and then adopted an emergy-based Life Cycle Assessment to compare two road scenarios (2014). Comparisons among road and other transportation systems (mainly railways) have been proposed by Federici *et al*. (2003; 2005; 2008; 2009) and by Threadcraft (2014).

5. An Italian case study

The case study at issue consists of a recent important deviation and expansion on the Apennine Mountains section of the Italian major highway A1, the so called "A1 var" section, opened to public in December 2015. The works lasted over ten years and costed 7 billion euros[3], with the expected benefits of saving travel time and fuel consumption due to the increased capacity and the higher quality of the service. Two independent studies were carried out (Cristiano, 2012, 2016) for an adjacent section, involved in the same broad deviation and expansion programme as the "A1 var" one, without finding significant savings in terms of pollution per unit of service (i.e., g/km per vehicle) nor hints of major improvements in terms of fuel consumption – although these studies only investigated indirect information such as the opening of the throttle valve. In the study at issue, expected benefits after the renovation works are verified and compared with the socio-environmental inputs required for construction in terms of emergy. Figure 1 reports the essential scheme which the analysis has been based on.

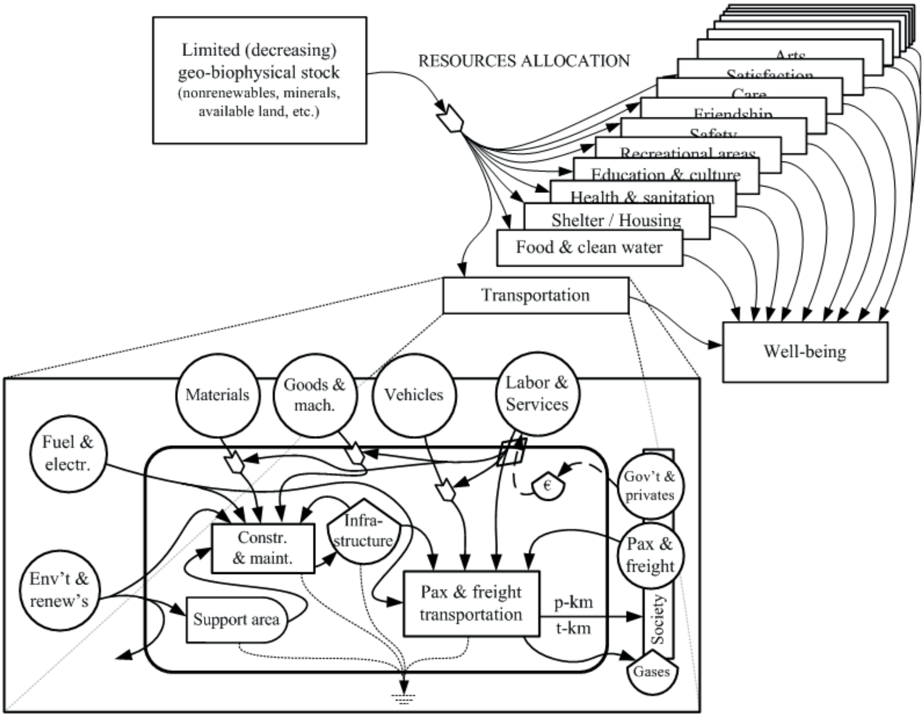

Fig. 1: Conceptual scheme for the analysis

3 http://www.rainews.it/dl/rainews/articoli/Apertura-della-Variante-di-valico-Renzi-Grande-emozione-non-ci-credeva-piu-nessuno-f60702bf-3008-455d-93d1-04db0b1df461.html

Some improvements are addressed for our case study, also in light of recent advances in emergy accounting research. Compared to the works by Federici *et al*. (2003, 2005, 2008, 2009), the services provided for free by nature to dilute pollutants are added, as in Reza *et al*. (2014) and – above all – following the procedure suggested by Ulgiati and Brown (2002), i.e. calculating the emergy associated with the wind energy to bring pollutants within acceptable concentrations as by legal limits. A further improvement is the calculation of the labour associated with the driving activity; this appears to be particularly suitable to describe major differences in what is expected from travellers in different transport modes (e.g., road driving or bicycle riding, or small-boat rowing versus driving-free road, motorised maritime, or air mobility), while requiring further discussion to understand its actual valence when making comparisons within the same transportation mode. It is worth noting that the output of the road transport infrastructure system may be addressed following different viewpoints, taking the form of sej/km, sej/passenger-km, or sej/tonne-km, in so emphasising either the investment referred to the structure build-up and maintenance or that related to the services provided to the public. This has some consequences in how the "vehicles" stock should be systemically framed within an emergy diagram. In the case of a systemic output defined as the sole physical highway, users vehicles do not play a role, whereas in the cases of systemic services expressed in terms of users' exploitation, vehicles are an input necessary for providing the output, and so has to be taken explicitly into account.

6. Discussion: time as "luxury"

A detailed presentation of the quantitative analysis is beyond the purpose of this contribution, and will be the object of the comprehensive study in preparation (Cristiano, Gonella, & Ulgiati, forthcoming). However, following the analysis of the addressed case study, one of the most interesting aspects is the quantitative role of time, that seems to be one of the keys for understanding the highway transport system from the point of view of its real sustainability. In fact, when opting for a new or renewed transport infrastructure (and when comparing for instance road mobility to rail mobility), saved time is likely to become a crucial reason in justifying civil enterprises (see for example the high-speed train projects proposed or realised all around the world). In the commented study, an overall advantage is not actually expected following the renovation works in none of the three functional units considered (functioning of the highway section per kilometre, emergy per passenger-kilometre, and emergy per tonne-kilometre). A situation close to a balance between benefits (input savings) and costs (input investments) is nearly achieved only if labour and services – including drivers labour – are accounted for. On the contrary, when drivers labour is not considered, the functional units are more emergy demanding, with the emergy per passenger-kilometre up to 25% higher and that per tonne-kilometre up to over 50% higher on the renewed section. It is worth underlining how emergy accounting output is generally given both with and without labour and services, since these might not describe properly any process and – at the same time – the question of standardisation in the way they are calculated is currently under debate in the emergists community. As per the emergy related to the drivers activity (labour), this is something definitely useful to account for and highlight the significant effort required in road transportation when compared to the minimisation of the driving responsibilities that characterise other transportation modes (rail, maritime, air), as after all done in conventional transport economics. When comparing two or more scenarios for a road transport system, instead, one might wonder whether or to what extent this information should be relevant, especially when considering that savings in time are not due to the instrinsic features of the same transportation mode, which cannot allow for alternatives presumably implying less resources consumption in operation owing – for instance – to the sharing of vehicles and fuel or electricity as for railways. In analyses of a same transport mode such as a road system, it seems that time saving might become the reason why a civil infrastructure is built or renewed, and such a goal is generally reached through the use of the resources and labour that we can financially afford from the privileged position *here and now*, often involving the exploitation of someone else's labour as well as the claiming of a right to use resources at the expense of people living in other areas (mainly in the Global South) or in the future (next generations). A real, winners/losers based "luxury". Yet, even for the most uncaring readers, the Odums (2001) ammonish that "[t]he auto age will come to an end when alternate needs for the fuels running the personal autos become more important than the time saved by having individual cars".

7. Conclusion

The results of the emergy synthesis here commented, if read while keeping in mind the wise words by Howard T. Odum and his wife Elizabeth (2001; 2006), warn us that such "luxury" highly depends on the abundance of energy (more generally, on the abundance of "cheap" resources and labour), i.e., of something which is less and less given for granted in a changing world undergoing a systemic crisis. Whether we want it or not – we will soon be led to reconsider our priorities due to the criticality and systemic unsustainability of a way of reasoning based on the aforementioned "luxury". Environmental sustainability and social equity might rather be reconsidered to turn this warning into an opportunity to pursue a lasting well being, which might include the recovery of *slowness* as a value, so that perhaps the labour-intensity of transportation could be judged on a case-by-case basis, with more (systemic) emphasis on the resource-intensity of a given transportation mode, including the evaluation of construction and maintenance environmental inputs. Framing an emergy accounting analysis in the more general picture of a prosperous way down is quite a complex task, but it is nevertheless one of the reasons why the donor-side perspective provided by the emergy conceptualisation was first established. Given the central role played by the transportation systems in defining the basic characters of any modern socio-economic system, it appears extremely important that an emergy analyis is carried out for the major transportation infrastructures, aiming at connecting a quantitative sustainability analysis with the mandatory transition towards a society where the fossil fuel will be no longer a focus of the overall productive activities.

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Evaluating rural developing dynamics using a combined emergy and niche method in a watershed

Dewei Yang

How to maintain rural residents' welfare and regional sustainability against the background of rapid urbanization is challengeable in China. The emergy and niche theory are most popular in eco-economic fields. It is widely applied to analyze regional competition in terms of socio-economic and environmental capitals. A combined emergy and eco-niche method is proposed to evaluate rural developing state and trends in a Jiulong Rvier watershed, southeast China. The data are collected from face-to-face survey of household activities, statistical yearbooks and land use data. We will analyze the competitive alternatives and identify regional sustainability, and also discuss how to survive for local residents under the background of rapid urbanization.

The environmental impacts of wheat straw-based lignocellulosic ethanol for transport sector in a prospective territorial biorefinery

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Abstract

The bio-ethanol (EtOH) is one of the most common biofuel and is foreseen as a leading candidate to substitute the gasoline in the transport sector among the European Union polices. Through the Life Cycle Assessment (LCA) approach, this study aimed to: (i) investigate the environmental performance of EtOH production from lignocellulosic wheat straw (WS) and its use as transport fuel in E10 (10% of EtOH and 90% of gasoline) and E85 (85% of EtOH and 15% of gasoline) vehicles, and (ii) further compare the results with similar bio-based systems from annual (fiber sorghum- FS) and perennial (giant reed- GR) dedicated crops as well as against the fossil counterpart (conventional gasoline passenger car). As one of the main outcomes of EnerBiochem and BioPolis projects, this work aimed to identify, from the environmental point of view, the best performing feedstock for a prospective territorial bio-refinery network in Campania Region (Southern Italy). The results showed for WS-E85 the relevance of the feedstock supply. The comparison highlighted for E10-blends similar profiles for most impact categories, nearly overlapping with the conventional passenger car. Differently, for E85 vehicles, the differences between the bio-based and reference systems appeared amplified according to the specific impacts of the feedstock supply and conversion steps. On the whole, FS-E85 system showed the worst environmental profile whilst WS-E85 entailed the best performance. However relevant potential constraints linked to the straw removal from the cropped fields need to be further investigated.

1. Introduction

There is an increasing interest in agricultural and forest residues as well as in dedicated crops (not in competition with food) capable to provide energy (Sims et al., 2006) and building blocks materials as alternatives to fossil fuel-based energy carriers and chemicals (Cherubini, 2010; Forte et al., 2017). In this regard, the International Renewable Energy Agency (IRENA) sets a 2030 energy target of about 20% of the global primary energy consumption from biomass conversion (IRENA, 2015). However some sustainability criteria should be respected: a minimum greenhouse gas saving of 60% for advanced biofuels from 2018 onwards (EEA, 2017). The bioethanol (EtOH) is one of the most common biofuel and it is foreseen as a leading candidate to potential substitute the gasoline in the transport sector among the European Union polices. The biorefinery technologies (Zucaro et al. 2016a), the bio-based products (Cherubini, 2010) and the final use of the products (e.g. fuel used in passenger car) should be evaluated considering current dependency on fossil products and the environmental consequences. The environmental life cycle impacts of the second generation bioethanol production were also largely determined by the types of biomasses (Zucaro et al. 2016b) and the system boundaries considered for the assessment (Luo et al., 2010; Parajuli et al., 2017). The lignocellulosic biomass thanks to its particular structure (in cellulose, hemicellulose, lignin, ash, and other residues) can be employed to obtain a wide spectrum of bio-products (Zucaro et al., 2016a; Forte et al., 2016; Forte et al 2017). In this study a detailed Life Cycle Assessment (LCA) was applied in order to evaluate and identify the major hotspots of the environmental performance of wheat straw (WS) based bio-ethanol (EtOH) used in E10 (10% of EtOH and 90% of gasoline) and E85 (85% of EtOH and 15% of gasoline) vehicles. Moreover, the comparison between different EtOH bio-based supply-use chains and the fossil counterpart (conventional gasoline passenger car) was carried out in order to assess the environmental potentials and constraints of a hypothetical local biorefinery plant in Campania Region.

2. Materials and Methods

2.1 Goal and scope definition

The aims of this study were to: (i) evaluate the environmental performance of wheat straw bioethanol (WS-EtOH) produced in a prospective local biorefinery plant (Campania Region) and used in E10 (10% of EtOH and 90% of gasoline) passenger cars or in E85 flex-fuel vehicles (E85, 85% of bioethanol and 15% of gasoline), (ii) address the comparison among similar bio-based systems from annual (fiber sorghum - FS) and perennial (giant reed - GR) dedicated crops on hilly marginal lands in the same territory (Campania Region), as well as over the fossil counterpart (gasoline passenger car), in order to identify the most suitable lignocellulosic feedstock.

An attributional cradle-to-wheel Life cycle Assessment (LCA) (ISO 144040, 2006; ISO14044, 2006) was applied, by means of SimaPro 8.0.3 software coupled with the ReCiPe (v.1.10, 2013) midpoint hierarchic impact assessment method. The impact categories analyzed were: Climate Change (CC), Ozone Depletion (OD), Terrestrial Acidification (TA), Freshwater Eutrophication (FE), Marine Eutrophication (ME), Photochemical Oxidant Formation (POF), Particulate Matter Formation (PMF), Water Depletion (WD), and Fossil Depletion (FD).

The analysed prospective biorefinery plant in Campania Region included the same Functional Unit, 1 km driving of a midsize passenger car, and an equivalent system boundary for WS-EtOH (as presented in Fig. 1), FS-EtOH (Forte et al., 2017) and GR-EtOH (Zucaro et al., 2016) supply-use chains as well as for the fossil reference counterpart. As it relates to the feedstock production, the analysis took into account the whole wheat cultivation for the co-production of wheat grains (sold to the market at the farm gate) and wheat straw (used into the investigated bio-based pathway). The wheat straw feedstock was then processed in an advanced second generation industrial plant including the pre-treatment, the enzymatic hydrolysis, pentose (C5) and hexose (C6) sugars co-fermentation, purification (Fig.1).

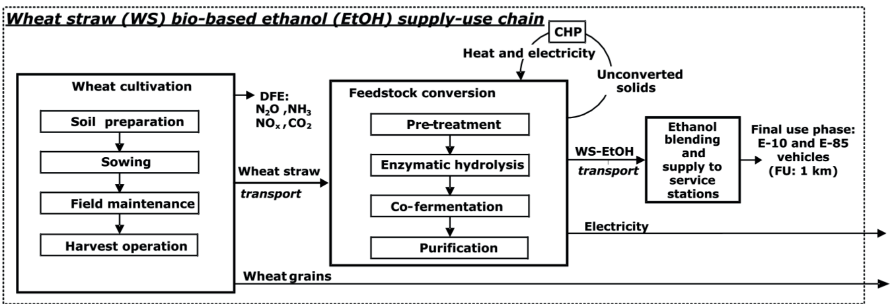


Fig. 1 System boundary of the wheat straw bio-ethanol (WS-EtOH) production-use chain in Campania Region. DFE: direct filed emissions;CHP: Combined Heating and Power-plant.

Moreover, the WS-EtOH system accounted the recovery of lignin cake (e.g. the lignin fraction and a portion of not hydrolyzed holocelluloses) and concentrated stillage (e.g. not fermented sugars and a portion of not hydrolyzed holocelluloses) in an Combined Heating and Power (CHP) plant to meet the facility's energy needs. An exceed of electricity was produced by the CHP plant and then sold to the local grid (energy surplus). Given the presence of very different co-products, according to the LCA procedures (ISO 14040, 2006; ISO 14044, 2006), in this study an economic allocation was considered as the most suitable approach. For the biomass production, the economic allocation was carried out on the basis of 10-year average prices for grains and straws of durum and common wheat (statistics downloaded from regional chamber of Camera di Commercio Avellino, 2015; Camera di Commercio Forlì-Cesena, 2015): 85% to grains and 15% to straw. Whereas, the impacts from the biorefinery plant were allocated by 99% to EtOH and 1% to the surplus electricity on the basis of average prices for EtOH fuel (0.5 €/L) and electricity (0.09 €/kWh) (Bai et al., 2010; Rauch and Thöne, 2012; ; Regulatory Authority for Electricity and Gas, 2015; Zucaro et al., 2016a).

Based on the specific blends fuel efficiency, the LHVs and the percentage of EtOH-petrol composition, the fuel economy was set as follow: (i) 0.063 kg of E10 fuel for driving 1 km (0.007 kg EtOH and 0.056 kg of gasoline) and (ii) 0.092 kg of E85 fuel for driving 1 km (0.079 kg of EtOH and 0.013 kg of gasoline) (Gnansounou et al., 2009; González-García et al., 2010; Zucaro et al., 2016a, Forte et al., 2017).

2.2 Life Cycle Inventory

The raw materials, energy use, manufacturing processes, transport, distribution, use and the final disposal of auxiliary inputs within and between each production stages were considered. Contrariwise, the cars production, maintenance and disposal were outside the analysed system boundaries for both the bio-based and fossil reference systems. The WS-EtOH supply-use chain inventory data was based on: (i) literature data for biomass production in the contest of Campania Region (Forte et al., 2016) and (ii) primary data for the feedstock conversion process by an advanced second generation technology (obtained in framework of EnerBiochem and BioPoliS projects) (iii) secondary data for the EtOH splash-blending stage and its final use in E10 and E85 vehicles.

Table 1 summarized for both the investigated passenger cars E10 and E85 the main inputs/outputs of the WS-EtOH supply/use chain. Only the inputs allocated to the wheat straw for EtOH production were showed, whilst the wheat grains produced (3.1 $t_{dry\ biomass}$ ha^{-1} yr^{-1}) at farm gate were directly sold to the market.

The transport of WS biomass from the farm gate to the biorefinery plant was assumed within a maximum radius of 70 km, by a mix of on-farm (tractors and trailers) and off-farm (20–28 ton diesel lorries) operations (regional short-supply chain, DM 2/03/2010). The biorefinery plant analysed was based on advanced second generation conversion technology allowing the conversion of about 420,000 t dry basis yr^{-1} of WS for the production of about 100,000 t yr^{-1} of EtOH. Industrial data were experimental estimates in the framework of EnerBiochem project. At this stage, all data inherent inputs and process efficiency represented sensitive industrial data, subject to disclosure restrictions. For this reason aggregated input/output flows are summarized in Table 1. The machineries and infrastructures used in the biorefinery plant (i.e. extraction and treatment of raw materials, manufacturing process, transport, distribution, use phase and the final disposal) were secondary inventory data retrieved from EcoInvent processes “Ethanol, 99.7% from wood biomass” and “Wood chips, burned in cogen 6400kWth, emission control” (EcoInvent database v. 2.2). In this regard, following the EcoInvent guidelines, the plant emissions from the CHP unit were modelled on the basis of dry matter and carbon content of the analyzed unconverted solids.

Table 1: Input and output flows of WS-EtOH production referred to the selected Functional Unit (FU= 1km).

Inputs of wheat straw agronomic practices [a]	Unit measure	E10	E85
Soil preparation			
Diesel for tillage, ploughing	L km^{-1}	1.27E-04	1.52E-03
Diesel for Tillage, harrowing, by spring tine harrow	L km^{-1}	2.15E-05	2.57E-04
Sowing			
Wheat seeds	kg km^{-1}	7.88E-04	9.43E-03
Sowing	L km^{1}	1.86E-05	2.23E-04
Urea, as N	kg km^{-1}	8.29E-05	9.93E-04
Fertilizing, by broadcaster	L km^{-1}	2.58E-05	3.09E-04
Field maintenance			
Urea, as N	kg km^{-1}	3.32E-04	3.97E-03
Fertilizing, by broadcaster	L km^{-1}	2.58E-05	3.09E-04
Tillage, currying, by weeder	L km^{-1}	7.80E-06	9.34E-05
Harvest operation			
Combine harvesting	L km^{-1}	1.62E-04	1.94E-03
Inputs at industrial plant			
Wheat straw (dry biomass)	t km^{-1}	2.76E-05	3.31E-04
Water [b]	kg km^{-1}	1.00E-01	1.20E+00
Enzyme solution and yeast inoculum	g km^{-1}	2.01E-01	2.40E+00
Total energy consumption [c]	MJ km^{-1}	1.26E-01	1.51E+00
Outputs at the biorefinery			
EtOH 99.7%	kg km^{-1}	6.58E-03	7.88E-02
Electricity surplus	kWh km^{-1}	4.21E-04	5.04E-03
Solid waste[d]	kg km^{-1}	3.54E-04	4.24E-03
Ashes [e]	kg km^{-1}	3.66E-04	4.38E-03

[a] The inputs amount of wheat cultivation were already allocated on economic basis between the two co-products, wheat grains (85%) and wheat straw (15%) and then referred to the selected functional unit. Detailed description on the data sources and the inputs/outputs per hectare of wheat cultivation in Campania Region are reported in a previous works by the same authors (Forte et al., 2016); [b] Net total amount (recycling included) used in pre-treatment, hydrolysis, fermentation, solid separation, distillation, together with the plant utilities (e.g. cooling tower); [c] Sum of electricity and heat consumption supplied through the combustion of unconverted solid in the internal Combined Heating and Power-CHP- plant; [d] To landfill disposal; [e] To open-loop recycling as soil amendment.

The transport of WS bioethanol was assumed as regional storage/distribution covering an average distance of about 150 km from the industrial plant to the service stations, through the combined use of 20–28 ton diesel lorries and freight-rail. The evaluation of the environmental performance of both E10 and E85 vehicles included the background data from the EcoInvent database (v. 2.02) for the gasoline production in accordance with the selected fuel economy (see section 2.1). The calculation of the tail-pipe emissions (i.e. CO, NO_X, NMVOC and greenhouse gases) related to the final car-use phase of E10 and E85 blends, were retrieved from pertinent scientific literature (Graham et al., 2008; Forte et al., 2017).

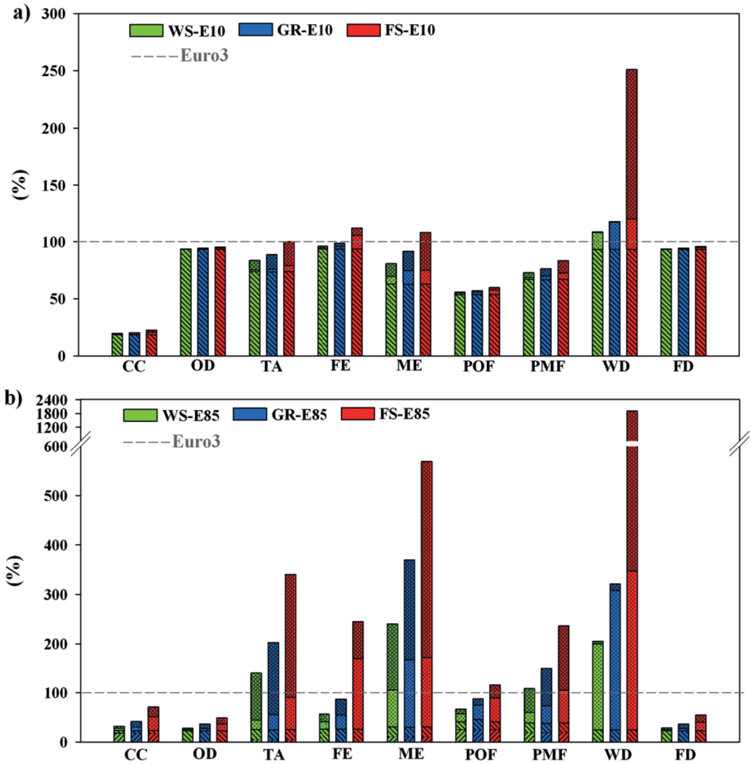
As regards to the reference system, the study referred to the record “Operation, passenger car, petrol, EURO 3” inside the EcoInvent product or process database, which allowed the comparison with bio-based systems on an equivalent system boundary, encompassing the crude oil extraction, its refining and distribution to service stations and the final gasoline use in a conventional midsize passenger car. The results achieved for the GR-EtOH and FS-EtOH supply-use chains were retrieved from the previous cradle-to-wheel LCA works published by the same authors (for detailed description see Zucaro et al., 2016 and Forte et al., 2017).

3. Results and discussion

Fig. 2 summarizes the total impacts linked to the WS-EtOH production-use chain and comparers the environmental profile of the WS-EtOH system (both as E10 and E85) with similar production-use chains based on perennial (GR) and annual (FS) lignocellulosic crops (Zucaro et al. 2016; Forte et al., 2017), in terms of percent decrease or increase with respect to the fossil reference system (conventional gasoline passenger car).

For the WS-E10, the main impacts (Fig.2a), for almost all impact categories, were related to the gasoline supply chain (EtOH blending and distribution stage). A separate discussion has to be made for CC (Fig.2a), where the tailpipe-emissions, were the major hotspots (79%) of the WS-EtOH system, whilst the fuel supply accounted for the remaining 21% (of which 20% was mainly related to the low sulfur petrol supply chain and only 1% was linked to the blended WS-EtOH). These outcomes confirmed the relevance of the low sulphur petrol supply chain and the tailpipe emissions, highlighted for similar lignocellulosic EtOH systems (González-García et al., 2009; Zucaro et al., 2016a; Forte et al., 2017). The potential impacts per km driven by WS-E85 flex-fuel vehicle (Fig. 2b) revealed an increased contribution of the crop phase. Specifically for TA, FE, ME and PMF the impacts were mainly related to the urea fertilizer input and the linked ammonia DFE from the cropped soil, ranking between 69% for TA and 28% for FE. The POF impact for WS-E85 was driven to similar extents by upstream (i.e. from agricultural machinery production) and downstream (tailpipe emissions, machinery operations and combustion at the CHP) emissions. Also for the water depletion the ratio of ethanol in the blend strongly influenced the total impact. Indeed, whilst for WS-E10 the WD impact (Fig.2a) was exclusively linked to the low sulphur petrol, for the WS-E85 vehicle (Fig. 2b) almost the whole WD impact (83%) came from the feedstock conversion facility (despite the water recycling, Table1), although the gasoline supply chain was not negligible (11%). The major driver of FD and OD impacts was the gasoline input for blending at service station (about 99% and 79%, respectively). As highlighted in many studies (González-García et al., 2009; Morales et al., 2015; Zucaro et al., 2016b; Forte et al., 2017) based on the LCA approach significant net reduction in green house gasses (GHG) emissions was found shifting from WS-E10 to WS-E85 blends. For the WS EtOH-gasoline mixes, the CC of E85 was about 66% less than for E10. The total CO_2 emissions (87% of total CC impact) for WS-E85 were mainly retrieved by the car use phase (64%), even if also for this impact category the crop phase (12%) and feedstock transport (7%) shared a relevant impact.

Comparing the results obtained for WS-E10 passenger car with GR-E10 and FS-10 vehicles, the bio-based systems showed similar profiles for the most impact categories, nearly overlapping with the conventional passenger car (Fig.2a). Nonetheless, WS-E10 performed better than the other lignocellulosic feedstock (markedly compared to FS-EtOH) in term of acidification, eutrophication and particular matter formation, which represented the most critical impact categories compared to the reference system (Fig.2a). For WD, WS-E10 confirmed the higher water consumption highlighted for GR-E10 and FS-E10 over the gasoline passenger car, due to the makeup water of the industrial processing (Zucaro et al., 2016a; Forte et al., 2017).



Impacts	$kg\ CO_2$ eq	kg CFC- 11 eq	$kg\ SO_2$ eq	kg P eq	kg N eq	kg NMVOC eq	kg PM10 eq	m^3	kg oil eq
WS-E10									
Total impacts	2.2×10^{-1}	3.1×10^{-8}	4.6×10^{-4}	6.5×10^{-6}	1.3×10^{-5}	3.4×10^{-4}	1.4×10^{-4}	8.6×10^{-4}	7.3×10^{-2}
Feedstock production	7.6×10^{-4}	8.2×10^{-11}	3.8×10^{-5}	9.0×10^{-8}	1.5×10^{-6}	4.2×10^{-6}	6.1×10^{-6}	3.5×10^{-6}	2.1×10^{-4}
Transport/conversion	2.0×10^{-3}	6.7×10^{-11}	7.6×10^{-6}	8.5×10^{-8}	8.5×10^{-7}	8.0×10^{-6}	2.7×10^{-6}	1.2×10^{-4}	1.5×10^{-4}
EtOH distribution/blending	4.4×10^{-2}	3.1×10^{-8}	3.5×10^{-4}	6.3×10^{-6}	8.5×10^{-6}	2.9×10^{-4}	1.0×10^{-4}	7.4×10^{-4}	7.3×10^{-2}
Car use phase	1.8×10^{-1}	0.0×10^{0}	6.5×10^{-5}	0.0×10^{0}	2.4×10^{-6}	4.2×10^{-5}	3.2×10^{-5}	0.0×10^{0}	0.0×10^{0}
WS-E85									
Total impacts	7.5×10^{-2}	9.3×10^{-9}	6.6×10^{-4}	3.8×10^{-6}	3.2×10^{-5}	3.6×10^{-4}	1.6×10^{-4}	1.6×10^{-3}	2.2×10^{-2}
Feedstock production	9.1×10^{-3}	9.7×10^{-10}	4.6×10^{-4}	1.1×10^{-6}	1.8×10^{-5}	5.0×10^{-5}	7.3×10^{-5}	4.2×10^{-5}	2.5×10^{-3}
Transport/conversion	1.1×10^{-2}	7.8×10^{-10}	9.0×10^{-5}	1.0×10^{-6}	1.0×10^{-5}	9.0×10^{-5}	3.2×10^{-5}	1.4×10^{-3}	1.8×10^{-3}
EtOH distribution/blending	1.2×10^{-2}	7.5×10^{-9}	9.2×10^{-5}	1.7×10^{-6}	2.6×10^{-6}	8.4×10^{-5}	2.8×10^{-5}	1.9×10^{-4}	1.8×10^{-2}
Car use phase	4.3×10^{-2}	0.0×10^{0}	2.6×10^{-5}	0.0×10^{0}	1.4×10^{-6}	1.4×10^{-4}	3.0×10^{-5}	0.0×10^{0}	0.0×10^{0}

Fig. 2. Environmental profile of a) E10 and b) E85 passenger car from wheat straw (WS-EtOH), giant reed (GR-EtOH) and fiber sorghum (FS-EtOH) feedstock as percent increase or decrease with respect to the fossil reference system (Euro 3, record "Euro 3, passenger car"). The inset table also shows for the WS bio-based system the absolute values of impacts for 1 km driven and the breakdown for the main sub-stages along the whole WS-E10 supply/use chain. Further details for the GR and FS bio-based systems and the reference system can be found in Zucaro et al.(2016) and Forte et al. (2017).

Mowing to the E85 vehicles, the LCA results were driven by the higher proportion of EtOH in the blend (Fig.2b) (González-García et al., 2009, 2010; Morales et al., 2015; Zucaro et al., 2016a; Forte et al., 2017). The differences between the bio-based systems (among each other and compared to the reference system) were tuned by the specific impacts of the feedstock supply and conversion steps (Fig.2b). For all impact categories, FS-E85 showed the worst environmental profile whilst WS-E85 entailed the best performance. The ranking observed reflected the hierarchy of impacts related to the crop phase. Indeed FS showed higher impact than GR (by about 50%) and WS feedstock (by about 74%) due to the annual management and the allocation procedure, respectively. Additionally, at the industrial stage, the EtOH yield. were in the following order: FS-EtOH (0.196 t $t_{biomass\ db}^{-1}$)> GR-EtOH (0.222 t $t_{biomass\ db}^{-1}$)> WS-EtOH (0.238 t $t_{biomass\ db}^{-1}$), according to the increasing percentage of cellulose and hemicelluloses in the "best feedstock composition" of the different biomasses (sensitive industrial data protected by nondisclosure agreements). With respect to the fossil system, WS-E85 confirmed and further strengthened the significant benefits already evidenced for GR-E85 and FS-E85 in terms of reduced GHG emissions and fossil energy use (Fig.2b). Moreover, WS-E85 increased by about 17% the saved life cycle GHG emissions over gasoline vehicles, as compared to the perennial based system (GR-E85), thanks to the sharing of emissions with grain production. Otherwise, notwithstanding the reduced impact of the crop phase, the environmental profile of WS-E85 related to the other categories ranged from comparable (for TA, FE, POF and PMF) to worse (for ME and WD) as compared to the conventional gasoline passenger car (Fig.2b). This finding confirmed the controversial issue about lignocellulosic biorefinery and biofuels pathways in terms of tradeoffs between the foreseen GHG and fossil energy saving and potential increased impacts in terms of acidification, eutrophication and water depletion (González-García et al., 2009, 2010; Morales et al., 2015; Zucaro et al., 2016a; Forte et al., 2016, 2017). Moreover, there are further key controversial environmental and economic issues to be addressed, which question the actual sustainability and feasibility of a prospective territorial biorefinery network based on WS feedstock: (i) the local availability of crop residues and the possible competition with alternative current uses in livestock and horticulture/mushroom sectors (Forte et al., 2016), (ii) the maximum removal rates of crop residues from agricultural land to avoid SOC depletion (Monforti et al. 2015), (iii) the potential increased inputs of synthetic fertilizers to compensate the loss of soil nutrients (Forte et al., 2016), and (iv) the lack of harmonization to allocate impacts between grains and straws.

Finally, in order to evaluate the sustainability of a prospective biorefinery network in Campania Region, the bioethanol should not be considered as the only output. In this regard, the co-production of added-value bio-chemicals should be considered as an effective pathway to implement the environmental performance of the whole system.

4. Conclusions

This study revealed that the agricultural crop residues are right now the more sustainable feedstock alternative (compared to GR or FS biomass) for bio-ethanol production in a prospective local biorefinery in Campania Region. Nevertheless, the environmental performance of WS-EtOH supply-use chain is controversial. From the one hand, for CC, OD, POF and FD substantial benefits were highlighted for both investigated EtOH-gasoline mixes compared to the fossil counterpart. Conversely, for all other categories (TA, FE, ME, PMF, and WD) the use of E10 and E85 blends showed comparable or mach higher impacts to gasoline. Additionally the availability of WS biomass not in competition with other current agronomic (soil incorporation) and zootechnical use need to be further investigated. Also further topics inherent to economic and social aspects (which were behind the scope of the present work) should be taken into account, since they can heavily affect the biorefinery system and market dynamics. Indeed, the issue of sustainability is complex and requires robust and integrated scientific studies in order to address an accurate global evaluation

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MuSIASEM approach to evaluate the pertinence of the second generation bioethanol production system. The case study of ligno-cellulosic *Arundo donax* feedstock for the transport sector in Campania region, Italy.

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Abstract

After the failure of first generation biofuels, the idea of next generation biofuels as sustainable alternative to fossil fuels is still followed to satisfy the energy demand of the transportation sector. The dominant narrative supporting biofuels, characterizes both first and next generation, it can be summarized in the following three points: (i) biofuels are promising sources of energy able to drive decarbonization strategies; (ii) biofuels can reduce fossil fuel dependency; (iii) biofuels can drive the local economy by way of the development of new technologies and revaluating marginal lands. Does the lignocellulosic bioethanol production system satisfy the expectancies promised from his narrative? The answer to this question can be achieved by means of a robust assessment able to integrate information from several domains in a common analytical framework. This paper presents a first analytical attempt (grammar definition) in applying the MuSIASEM approach to a feasibility study of lignocellulosic bioethanol production in Campania Region (Italy).

1. Introduction

In spite of the criticisms and the failure of first generation biofuels (from food feedstocks) (Giampietro and Mayumi, 2009; Gomiero, 2015 and references therein), in the last decades, the idea of next generation biofuels as sustainable alternative to fossil fuels, mainly to be used in transport sector, is still gaining broad attention among scientists, politicians and stakeholders (Gomiero, 2015). In fact, with reference to European context, EU policy supports the use of renewable sources, regulated by Directive 2009/28/EC, also known as the "20-20-20" targets, that set as objective for EU the achievement of a share of 20% from renewable sources in 2020 in the consumed energy mix (Directive 2009/28/EC). Such political stance is priming private and public investments. The focus shifted from first generation biofuels to next generation biofuels (cellulosic ethanol and biofuels from algae). Biodiesel and bioethanol are biofuels mainly conceived to satisfy the energy demand of transport, a highly energivorous sector of the developed societies. For example, transport sector in EU countries for the year 2014 contributed for the 33.2% of the gross consumption of energy, estimated in 1,605.9 million tonnes of oil equivalent (Eurostat statistics). According with forecasts of the International Energy Outlook (EIA, 2011), world energy consumption is expected to increase by 53% between 2008 and 2035 (1.6% per year), stimulated in particular by the industrial and transport sector. The transport sector has been relying for about 97% of the supply on fossil fuels (IEA, 2011) so far accounting for 27% of total world delivered energy consumption (IEA, 2011) and 22% of the overall GHG emissions in 2008 (IEA STATISTICS, 2010). Global demand for transport appears unlikely to decrease in the foreseeable future; the world energy outlook 2009 projects that transport will grow by 45% by 2030. Increasing demand for personal travel in the growing economies, freight and goods transportation system expansion along national and international routes are the main drivers of the utilization growth rate, which is expected to increase by 1.4% per year from 2008 and 2035 (EIA, 2011).

The dominant narrative supporting biofuels, among the various actors (scientists, policy makers and stakeholders), characterizes both first and next generation. It involves environmental and socio-economic motivations and can be summarized in the following three points: (i) biofuels are promising sources of energy able to drive decarbonization strategies; (ii) biofuels can reduce fossil fuel dependency; (iii) biofuels can drive the local economy by way of the development of new technologies and revaluating marginal lands.

Second generation biofuels are considered as the best option as it does not compete directly for use for food, does not require large amounts of inputs in terms of annual cultivation and fertilizer application, nor involve the destruction of native terrestrial ecosystems, with consequents negative effects on carbon sequestration and biodiversity. The “concept of marginal lands” represents a key topic in the narrative of biofuels, since it would overcome the conflict over land use (food vs. fuel). Therefore, a new trend on research and innovation was developed in the matter of energy crop production and conversion from lignocellulosic non-food crops and considerable resources worldwide have been invested in the last decades on topic. Second generation bioethanol is the most common biofuel and it is a leading candidate to potential substitute the gasoline as a transport fuel. Several dedicated second generation feedstocks are proposed, among them perennial crops are considered promising since they have high yields, competitive energy ratio, low agronomic input, concomitant reductions in greenhouse gas emissions and generally favourable effects on soil carbon storage. *Arundo donax* L. (common name giant reed) is one of the perennial crops considered as one of the most suitable cultivation in the Mediterranean environment (Zucaro *et al*., 2016).

Upham et al (2011) highlighted that biofuel policy development has arguably been unduly non-responsive to critical opinion, given the limited scientific base on biofuel impacts. This is due to the dominant studies approach; even if they have utilized robust methods, largely strength and recognized by scientific community. Despite the wide number of scientific publications and sector’s studies produced on topic, to date, they have the large limit to apply a reductionist approach, since related to specific processing phase or sector. Studies aimed at assessing the sustainability of large scale biofuel programs have generally focused on a few variables related to one scientific domain and one scale. For example, agronomic studies are mainly characterized in the evaluation and selection of appropriate crops with low agronomic input, in relation to the local land use and attractiveness for farmers. Even, technical studies are referred to improve physical, chemical and microbiological feedstocks’ transformation processes, with the aim to improve product yield and to reduce the energy ratio of the overall production chain. While, economic studies are largely still penned in sector studies of companies and then protected by secrecy with aggregated foreground data barely verifiable (grey literature). Notwithstanding the reductionist approach, the literature uses largely the adjective “promising” to generate a broad acceptance on the sustainability of such energy product. To the best of the author's knowledge, an integrated assessment of the implications and constraints of large-scale biofuel production and use is still lacking.

The pertinence of second generation bioethanol, according to sustainable paradigm, needs a holistic view and integrated studies to achieve a comprehensive picture to drive any proper decision. To this aim the studies have to be built on: (i) robust conceptual framework: (ii) proper quantitative and qualitative characterization from the different domains, in order to evaluate the comprehensive system performance and its viability; (iii) participative process among the several actors (policy-makers, stakeholders, citizens). End-users need to be provided with proper multi-criteria decision analysis tools/systems in order to identify the suitable performance of the future energy supply systems in terms of environmental, social and economic performance. Only such approach can fulfil useful information to satisfy bioethanol narrative.

This contribution aims to generate an analytical framework able to provide an answer to the following question: does the lignocellulosic bioethanol production system satisfy the expectancies promised from his narrative? The integrated assessment was framed within the rationale of the holistic Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) accounting method (Giampietro et al., 2014) developed as an integrated evaluating tool for the analysis of complex adaptive systems.

The study was carried out within the "EnerbioChem project" (PON01_01966, 2012–2015) aiming to perform a feasibility study of a bioethanol production system to be realized in Campania Region (Southern Italy), based on large scale experimental data of giant reed feedstock cultivated in marginal lands and second generation technologies for the feedstock conversion by means of the innovative patented pretreatment developed by Italian company (details in Zucaro et al, 2016).

1.2 Study system

The "EnerbioChem project" aimed to furnish a territorial evaluation to recover the economic profitability of marginal lands by means of the development of a regional biorefinery (Campania Region, Southern Italy). Potential marginal area was recognized in hilly wheat belt, corresponding to almost 150k ha, coming up to the Appennino mountain chain ridge. This wide territory, corresponding to 27% of the overall Campania's agricultural surface, has lost in the recent years the high economic profitability due to the soil reduced fertility caused by wheat cultivation. One of the feedstock tested in the project, was *Arundo donax* L. (common name giant reed). This crop was selected since it is considered a perennial crop able to protect soil from weather aggressiveness, to accumulate soil organic matter and it is characterized by low agronomic inputs. Figure 1 describes summarily the main characteristics of the BioOH-PS; more detailed information in Zucaro et al. (2016). The study has evaluated second generation biorefinery plant based on the innovative technology for the feedstock conversion. The plant has a feedstock transformation and biofuel productive capacity amounted to 450,000 dry t yr^{-1} and 37k toe, respectively. This study considers the use of bioethanol to fuel E85 cars (85% EtOH and 15% gasoline) since the environmental performance evaluated by Zucaro et al. (2016) appeared favourable only for this engine type.

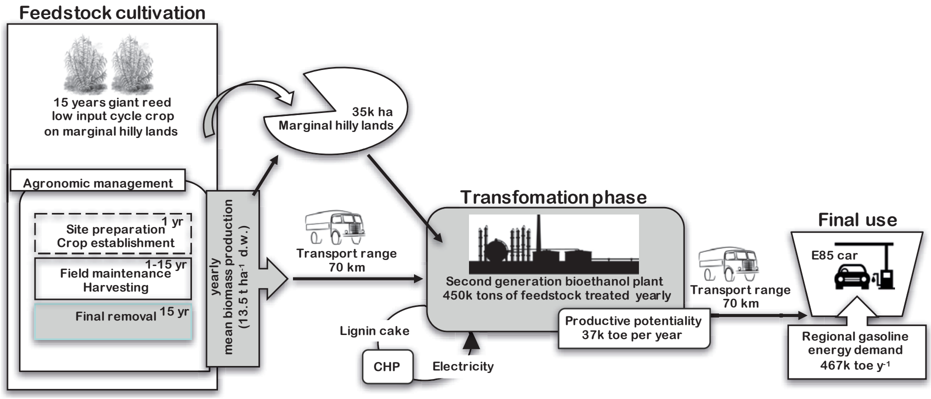

Fig. 1: Representation of the BioOH-PS evaluated in the study.

1.2 Study framework

The feasibility assessment of any biofuel production system has to cope with a complex system, characterized by the combined effects of several factors from different domains and reflecting non-equivalent views. Among these, the bio-physical capacity of the territory, the societal energy demand, the technical and environmental performance of the production chain, the expected social and monetary benefits. Since such new energy production system may deeply change land use and affect socio-economic perspectives, an integrated assessment has to be performed in order to obtain a watchful picture, addressed into the relevant perspective and able to identifies the different point of views.

The evaluation of the sustainability of second generation bioethanol is currently approached by comparison with fossil counterpart. This approach is particularly evident in LCA studies where bioethanol is conceived as a “package of energy”, with a defined production chain, to be compared with other “package of energy” with similar function but different characteristics. Such approach appears little relevant since the comparison is between two different systems. Moreover, the comparison of the environmental performance, mainly focused on climate change saving, even if aimed to determine the reduction percentage, is self-evident since the use of fossil fuel represents an uptake of the large carbon fossil sink, while energy from biomass is a closed carbon loop.

The real matter is to understand what the system does and how it interacts with its context. Therefore, the real matter is to evaluate at what degree bioethanol, in the short time, is suitable to replace gasoline in the high energivorous and worldwide growing transport sector, currently based on the gasoline’s characteristics (high power density, current low economic costs, low human labour, current cars fleet and so on). Very difficult is to evaluate, in the long term, the effectiveness of bioethanol to satisfy the energy needs of transport sector, since technical, environmental and socio-economic scenarios are not predictable since they are complex dynamic systems. Therefore, the pertinence of bioethanol has to take into account the large current use of energy in the transport sector, affecting the local bio-physical capacity as land use (large area for feedstock production due to the very low power density) and environmental impacts (not only climate change effect) as well as social desirability (real advantage for the local employment taking also into account others land use scenarios). In the final analysis, we have to evaluate the survival capacity of the new energy production system (BioOH-PS). So, the most suitable approach is the evaluation of the survival capability of the new metabolic system (BioOH-PS) when it has to substitute partially (short term) or definitively (long term) gasoline system. Within the rationale of the societal metabolism, BioOH-PS is perceived as a metabolic system that modulates the interaction between the metabolic needs of the society for energy use in transport, which uses funds and flows (land, matter, energy, human labour, money) and generates several flows of output (money, pollution, energy degraded, etc). From a technical point of view, BioOH-PS is a specific “human managed metabolic system” for a “fast” solar energy transformation in liquid fuels. The adjective “fast” is relative to fossil fuels that are the results of a gradual ancient accumulation of solar energy in the biomass of photosynthetic organisms. The transformation process, from cultivated feedstock to final product, may be framed in two stages: agronomic phase and feedstock technological transformation. Crops production apply typical modern agronomic management, requiring infrastructures, energy and matter flows for soil management, fertilization, irrigation and transport. Even if, recently large attention has been dedicated to low input crops and several techniques are developing, mainly in the field of bio-technologies, with the aim of improving the productive yield and reducing the environmental impacts of the overall production chain.

MuSIASEM approach (Giampietro et al, 2014), considers simultaneously different types of variables (environmental, economic, social, and technical) in a coherent and comprehensive accounting framework also integrated across scales. All these factors are non-equivalent and are differently conceived by the several actors. For this reason, MuSIASEM envisions two non-equivalent views of the system under analysis: the outside view and the inside view. In this study, the reference framework used in identifying the two points of view was the narrative used by the investors that need to establish a bio-refinery for energy purpose in a territory. An overview of the semantic and analytical framework of the BioOH-PS is showed in Fig. 2, representing the structural and functional elements of the system. The elements are summarized in the processor analytical concept, that specificate the expected mix of inputs and outputs required to carryout a specified process (task) within an element of the multi-scale metabolic pattern.

The semantic framework of the ***inside view***, considers technical and economic parameters that, together, determine the “operating capacity” of the system that will satisfy the narrative. Among technical parameters, we may include: (i) plant design and its average life; (ii) the nature and the amount of feedstock, commensurate to the processing capacity of the plant; (iii) transformation yield of the feedstock, strictly linked with technical know-how; (iv) energy and matter requirement for the plant operation; (v) environmental performance of the overall system (product chain + plant construction and operation). Among economic factors we can include: (i) monetary cost of plant, spread for the average life; (ii) feedstock’s monetary cost; (iii) monetary cost of the feedstock transformation phase; (iv) monetary cost of the employers; (v) biofuel’s price of sale. The ***outside view*** provides relevant information about the role of some factors outside the BioOH-PS control, affecting its operating capacity. This view focuses on the environmental, social and economic constraints (flows and funds). In this view we may consider: (i) land use (even if second generation biofuels are conceived using marginal lands not in competition with food, large land use is predictable to satisfy the high energy demand for transport sector); (ii) the environmental performance (energy and matter consumption plus pollutants outputs) of the entire production chain (from cradle to wheel); (iii) availability of labour force affected by local social dynamics; (iv) availability of labour force affected by profitability of feedstock production; (v) power capacity of machineries; (vi) societal energy demand for transportation sector.

The selection of relevant variables for inclusion in the analysis is affected by different factors: the nature and the goal of the study, the available collected data and so on. Moreover, the choice of relevant variables should be semantically open and can be continuously changed thanks to the inclusion of the end-users (overall actors) in the discussion. Similarly, final decisions should be characterized by the same participatory process, based on the results of the scientific analysis.

Framing the analysis of BioOH-PS within this rationale we have generated three criteria of performance; in the jargon of the analysis they are: feasibility, viability and desirability.

Feasibility: it represents the performance related to external constraints. Specifically, we considered: (i) the territorial bio-physical capacity in terms of land use and yield capacity, to guarantee the amount of feedstock to be transformed in bioethanol; (ii) human labour, as the territorial potentiality to furnish labour force and time of human labour specifically dedicated in the overall production chain; (iii) local and external environmental impacts of the whole production chain. Distinction between local environmental impacts (i.e. inside administrative boundaries) and external environmental impacts (i.e. outside administrative boundaries) are fundamental since it could generate responses as social desirability, for example affecting other territorial economic sectors.

Viability: it is the performance in relation to internal constraints of the BioOH-PS. We specifically considered: (i) economic costs; (ii) the stakeholder's perception of BioOH-PS; (iii) technical coefficients (transformation efficiency, technical know-how, energy investment, power density, feedstock intermittency).

Desirability: it is the performance in relation to the social actors involved. They are mainly represented by consumers, policy-makers but also by other territorial economic sectors that can be affected by territorial presence of BioOH-PS.

By means of proper flow/fund ratios the production processes will be characterized at different scales of analysis, in order to obtain the whole picture of the metabolic pattern and its level of openness.

Such approach allows: (i) to avoid the restricted simplistic comparison between two different systems (bioethanol and gasoline); (ii) to generate a conceptual framework for the feasibility study of any metabolic system and specifically tailored for each socio-economic context; (iii) to produce robust and reliable evaluation framework, as well as easily understandable output (the overall performance) for end-users, where a top-down route (*ex post*) allows to generate an *ad hoc* participative evaluation in order to improve the bottom-up analysis (*ex ante*). This procedure can be used as decision support system for carrying out an informed choice, based on the simultaneous consideration of different performance parameters from different domains.

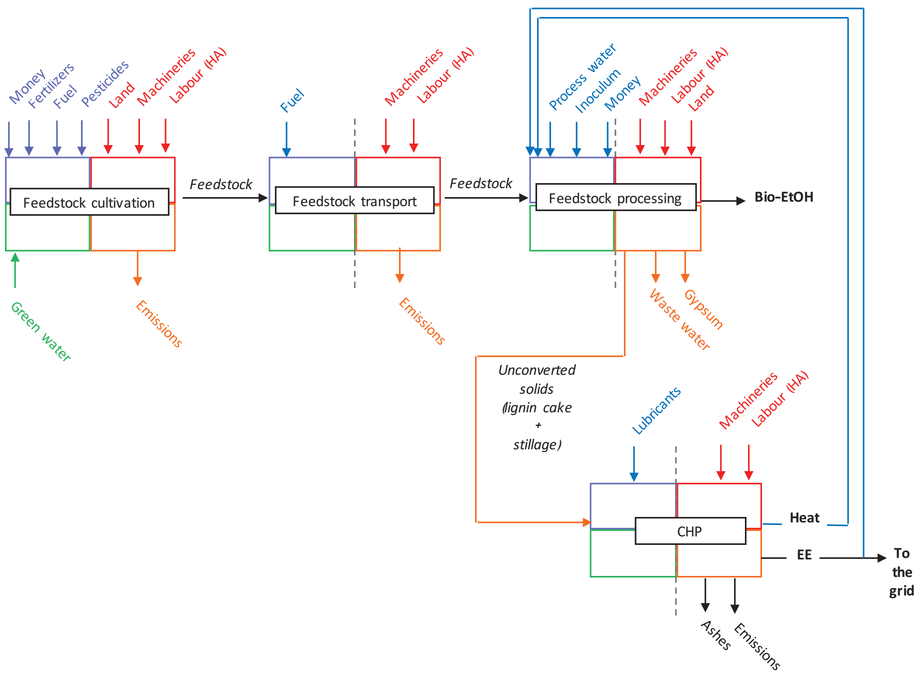

Fig. 2: Processor scheme representation of the studied production system.

Acknowledgement

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Is Transport-Energy-Emission Nexus Possible? A Literature Review of Transport Energy Demand and Emissions at the Regional Level: using JingJinJi as Case Study

Steve-Wonder Amakpah, Gengyuan Liu, Marco Casazza, Biagio F. Giannetti and Sergio Ulgiati

Urban transportation energy demand continues to grow astronomically, alerting many governments to combine cities into regional economic hubs and an example is Jing-Jin-Ji (Beijing, Tianjin Hebei) in China. Research shows that the transportation energy efficiency of high-density, multi-core cities, is higher than that of single-core or mononuclear cities. However, characteristic of urbanisation is increasing population that increases transportation energy and infrastructure needs, and expansion of logistics/services sector with resultant high levels of emissions. Due to the direct linkage between transportation, energy, and emission, it is important to study the effect, the challenges and the opportunities available particularly in a multi-core city level. Further, to reflect the question of "whether or not a nexus of transport-energy-emission is possible?" can be interesting. This paper reviews the dependence of urban transportation on energy and focuses on two identifiable studies Transport-Energy and Transport-Emission Nexus respectively. First, it explores existing literature on urban transportation energy demand regarding energy types. Secondly, it reviews the literature on the factors influencing the growth in transport energy demand with keen attention to particles emission and public health risks. Thirdly, it examines any possibility of previous literature that dealt with the tripartite synergy of Transport-Energy-Emission. Fourthly, it summarises the current research methods used. Finally, the main advances and research gaps in current literature are summarised based on previous studies. In conclusion, we establish that the understanding of the synergy between transport-energy demand and transport-emission respectively is not enough. It is also very crucial to study the possible existing nexus of Transport-Energy-Emission of an urban system to enable the implementation of effective and more efficient transport infrastructure, energy policies; including but not limited to optimising energy demand in transport and reducing transport-related emissions in the Jing-Jin-Ji region.

Net energy availability and environmental performance of the Chilean electricity grids: potential for improvements

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Abstract

Chile has become one of the fastest-growing countries in Latin America over the past decade, with an electricity demand that is expected to increase from approximately 70 TWh/yr to over 100 TWh/yr by 2020. Also, Chile is experiencing a radical change in its electric grids, including high penetration of solar photovoltaic systems. This ongoing transition is due to the ambitious national target to generate 60% of the country's electricity from renewable energies by 2035, as well as the 2014-2018 Energy Programme that aims to achieve a 45% renewable energy share for new electric capacity installed between 2014 and 2025. This paper presents a comprehensive analysis of the energy performance of all the individual electricity generation technologies as currently deployed in the two main electric grid systems in Chile (SING and SIC). The Life Cycle Assessment (LCA) and Net Energy Analysis (NEA) methods are applied in parallel to provide complementary indicators and identify the current weak spots. Results have shown that the simultaneous and synergistic deployment of more PV and wind (and potentially, hydro) systems appears to be the most promising strategy for both the SIC and SING grids.

1. Introduction

Over the past decade, Chile has become one of the fastest-growing countries in Latin America, and its population is projected to grow at an average annual rate of 0.6%, reaching over 20 million by 2035. Chile is also a net importer of energy, and its largely fossil-fuelled electricity demand is expected to increase from approximately 70 TWh/yr to over 100 TWh/yr by 2020[1] (Ministerio de Energía, 2015).

To address this energy security issue, as well as reduce its carbon intensity, Chile is embarking on a radical energy transition with ambitious targets: to generate 60% of its electricity from locally-available renewable energies by 2035, and 70% by 2050. Its 2014-2018 Energy Programme also aims to achieve a 45% renewable energy share for all new

[1] www.worldenergyoutlook.org

electric installed capacity between 2014 and 2025 (IRENA, 2015; Ministerio de energia, 2015).

Currently, power generation in Chile is organised around four independent electric grid systems, the two principal ones being the Sistema Interconectado Central (SIC), and the northern Sector Interconectado del Norte Grande (SING). The SIC grid covers the central and southern regions of the country, including the main consumption centres around the capital Santiago, while the SING grid mainly supplies electricity to the mining and mineral industries in the north of the country (Ministerio de energia, Gobierno de Chile).

The main purpose of this work is the evaluation of the energy performance of all the generation technologies as currently deployed in the two main Chilean electricity grids (SIC and SING), including a detailed weak spot analysis. This work is also intended to serve as a starting point for future research on potential scenarios of electricity generation with a larger deployment of renewable energies, with special focus on the SING region.

2. System description

The systems considered in this study comprise of the generation technologies as currently deployed in the two main Chilean electricity grids (SIC and SING), with 2016 as the chosen baseline year. In all cases, the chosen functional unit (FU) is 1 MJ of electricity delivered.

On the whole, Chile has two major domestic energy resources for electricity: wood for biomass generation and water for hydroelectricity generation. At the same time, though, Chile has only limited domestic fossil energy resources, which exposes its economy to important risks in terms of energy security.

In 2016 all of Chile's coal was imported, coming from Colombia (~42%), the USA (~33%), Australia (~21%) and Canada (~3%). Historically, Chile's main source of imported natural gas was Argentina, but since 2004 it has faced import restrictions, which have led to pursuing other sources of imports in the form of liquefied natural gas (LNG), which currently comes from Trinidad and Tobago (79%) and Norway (21%). Also, crude oil is imported from Brazil (62%) and the USA (38%), and diesel is imported from the USA[2].

The SIC electricity mix in 2016 was composed mainly of thermoelectric electricity (~50%) and hydroelectric power plants (~35%), while the contribution of wind, PV (Grágeda et al., 2016) and biomass electricity cumulatively accounted for less than 15% of the total electricity generated. The SING grid is even more heavily reliant on fossil fuels (~90% of the total electricity demand), especially coal, with notably no hydro capacity[2].

3. Methods

In this work – like in previous published studies (Raugei and Leccisi, 2016; Leccisi et al., 2016; Jones et al., 2017; Raugei et al., 2017) – the choice was made to jointly apply two complementary methods that share common elements in structures and procedures, namely Life Cycle Assessment (LCA) and Net Energy Analysis (NEA).

LCA's principal energy indicator is the cumulative energy demand (CED), measuring the total primary energy (PE) that must be harvested from the environment to produce a given amount of usable product or energy carrier (Frischknecht et al., 2007, 2015). Also, LCA differentiates between renewable and non-renewable energy resources and flows, and the non-renewable primary energy that is harvested per unit of system output over the full life cycle is referred to as non-renewable cumulative energy demand (nr-CED). LCA addresses a number of emission-related impact categories too, such as global warming, acidification, ozone depletion, human and eco-toxicity, etc. However, these will not be discussed in this article as they fall outside the scope of the current work.

NEA then provides a valuable alternative viewpoint on the energy performance of a system (Carbajales-Dale et al., 2014). Its principal metric is the Energy Return on Investment (EROI), which measures the ratio of the energy delivered to society by the analysed system to the sum of energy inputs invested in the supply chain and all stages of the life of the system (the latter accounted for in terms of primary energy). As discussed elsewhere (Raugei et al, 2016; Raugei and Leccisi, 2016; Leccisi et al, 2016), the EROI of electricity may be expressed either in terms of direct electricity output ($EROI_{el} = Out_{el}$ / Invested) or in terms of its equivalent primary energy ($EROI_{PE\text{-}eq} = Out_{PE\text{-}eq}$ / Invested). In order to side-step the added complexity deriving from $EROI_{PE\text{-}eq}$ being a metric of performance that also depends on the efficiency of the grid mix as a whole, in this work we shall focus on discussing the $EROI_{el}$ indicator.

4. Results

Figure 1 illustrates the resulting $EROI_{el}$ of all the analysed electricity generation technologies (in terms of MJ of electricity output per MJ of primary energy investment) as deployed in the SIC and SING grids.

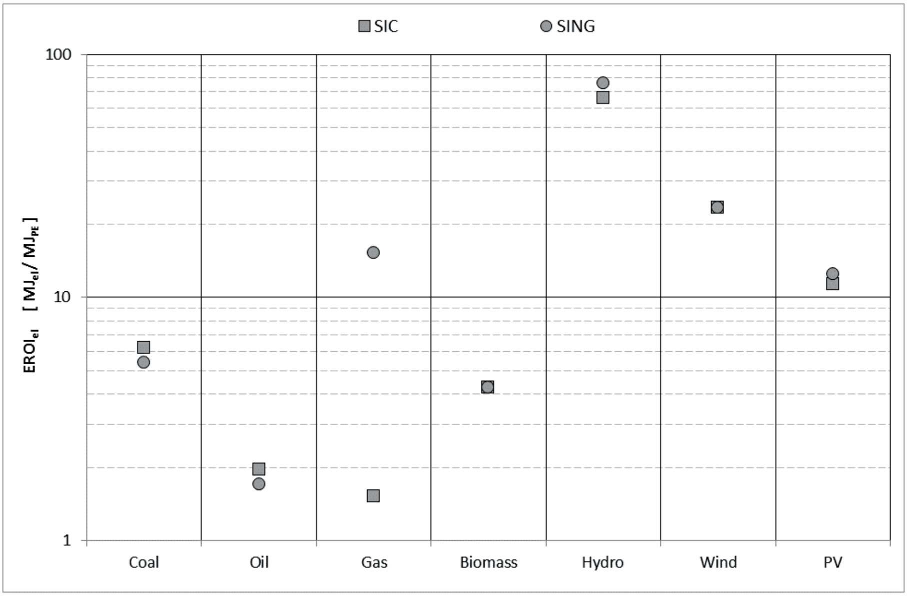

Figure 1 - $EROI_{el}$ results per technology (N.B. values expressed as MJ of electricity output per MJ of primary energy investment).

First of all, for all the conventional thermal energy technologies it is of paramount importance to differentiate between the EROI of the feedstock fuel at source and the EROI of electricity.

Specifically, the EROI of coal at source (i.e., at mining sites in the supplying countries) is on average still quite high (~50-75), but the subsequent energy investment for the transport of imported coal (which represents 70% of Chilean supply) takes a considerable toll, reducing the average EROI of coal feedstock to Chilean power plants to ~20. The low thermal efficiency of coal combustion (34% for SIC power plants and 29% for SING power plants[2]) then further reduces the EROI of coal-fired electricity to ~6.

Compared to coal, the EROI of crude oil at the well head (sourced from Brazil and the USA) is lower to begin with (~24), and is then reduced due to the energy investment to operate the refinery to produce Diesel oil (EROI ≈ 6), which is then combusted to obtain diesel-fired electricity ($EROI_{el}$ ≈ 2). From a Net Energy Analysis (NEA) perspective, therefore, *oil-fired electricity is not an effective option in Chile*.

As to natural gas, its EROI at source is typically very high (>100); on the other hand, since the gas is then supplied to the SIC grid in liquefied form (LNG), and the liquefaction process is energy demanding (The Oxford Institute for Energy Studies, 2016), the EROI of LNG dramatically decrease to ~5. The subsequent combustion process in the power plant (heat ratio = 33%) then further reduces the EROI of gas-fired electricity in the SIC grid to a worryingly low 1.5. Therefore, while still useful as a readily dispatchable technology to balance supply and demand, *gas-fired electricity seems to contribute very little, if anything at all, to the overall net energy gain of the SIC grid*, despite constituting almost 20% of the SIC grid mix. Natural gas is instead supplied directly to the SING grid, via the "Gasoducto del Pacífico" pipeline from Argentina[3]. This allows it to maintain a healthy EROI ≈ 34 as a feedstock, and subsequently $EROI_{el}$ ≈ 15.

The $EROI_{el}$ of biomass electricity is heavily dependent on the specific type of biomass feedstock that is used, as well as on the associated supply chain. In Chile, it appears that a majority of the biomass used for electricity production comes from domestic forestry residues, in the form of woodchips, bark, and prunings. These are all relatively low-energy intensive to harvest and transport, and hence the high EROI of the biomass feedstock supply (~30). Due to a low average combustion efficiency of ~15% (CNE, 2016), though, the final $EROI_{el\ of}$ biomass-fired electricity is ≈ 4.

The $EROI_{el}$ of hydro electricity generation in the SIC grid is very high (~70), due to the long-lived structures and relatively high capacity factors (39%[4]) (CNE, 2016), which result in a very low level of energy investment per MJ of electricity generated.

The $EROI_{el}$ of wind electricity (100% on shore) is also very high (>20), which is also helped by a relatively high capacity factor (35%). Finally, the $EROI_{el}$ of PV electricity generation is likewise also relatively high (~11), also thanks to the exceptionally high equivalent irradiation levels (up to 4,000 kWh/(m^2*yr) when including the effect of 1-axis tracking[5] (Fthenakis et al., 2014)), and ensuing capacity factors (respectively approx. 29% and 31% for SIC and SING)[6].

Figure 2 illustrates the nr-CED results (in terms of MJ of total non-renewable primary energy input per MJ of electricity output).

As expected, the performance of coal-, oil- and natural gas-fired electricity is broadly similar in terms of the demand for non-renewable energy, with roughly 2.5 - 5 units on non-renewable primary energy required per unit of electricity delivered (with gas at the lower end of the scale, and coal at the higher end).

Biomass-fired electricity fares much better, with an order-of-magnitude reduction in the demand for non-renewable energy per unit of electricity delivered over its full life cycle. It is noteworthy, though, that biomass energy performance is still significantly worse than that of

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[2] https://www.cne.cl
[3]http://www.cge.cl/sector-gas/gas-natural/gasoducto-del-pacifico/
[4] The value reported is for 2016. However, it should be noted that the CFs of dammed hydro have been negatively impaired by heavy droughts during the last 5 years.
[5] The vast majority of the large-scale PV plants in Chile employ 1-axis tracking systems.
[6] https://www.cne.cl

the non-thermal renewable technologies (hydro, wind, and PV), because of the comparatively larger use of fossil fuels in the biomass feedstock supply chain.

Hydro electricity generation is once again the best-performing technology, with a further order of magnitude improvement (nr-CED < 0.02 $MJ_{nr\text{-}PE}/MJ_{el}$).

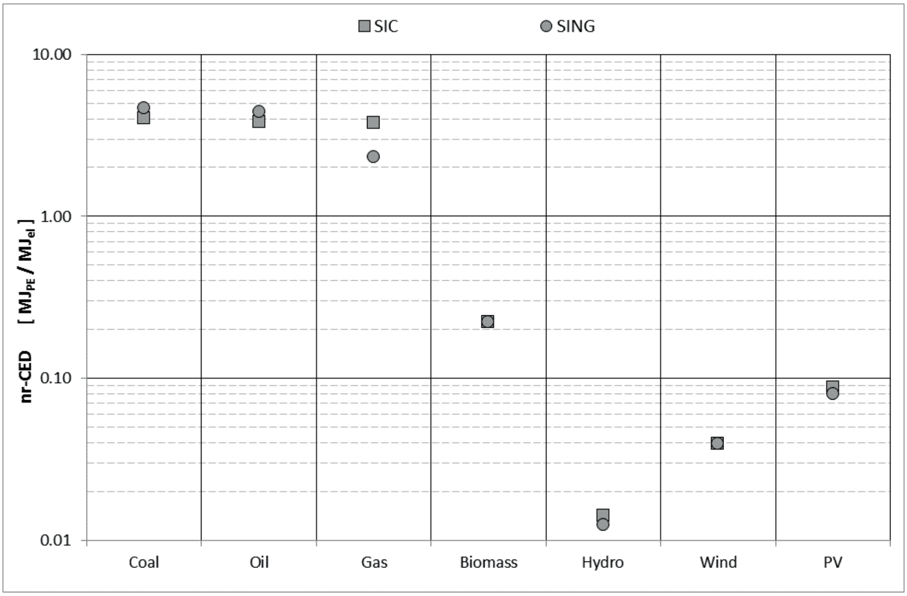

Figure 2 - nr-CED results per technology (N.B. values expressed as MJ of total non-renewable primary energy input per MJ of electricity output).

Finally, both wind and PV electricity present very low non-renewable cumulative energy demand per unit of electricity in absolute terms (< 0.1 $MJ_{nr\text{-}PE}/MJ_{el}$); this performance is achieved in part thanks to the optimal environmental conditions that are present in Chile (wind and irradiation), resulting in favourable capacity factors for these technologies. Once again, though, energy storage and curtailment may play a role in future scenarios of large-scale deployment of these technologies.

5. Conclusions

From a Net Energy Analysis perspective, the most promising technologies to improve the overall performance of the Chilean grid mixes appear to be PV[7], hydro, wind and gas. However, these results come with a number of caveats. On one hand, wind and PV electricity production is inherently intermittent, and deploying large capacities of either technology may only be possible if suitable power transmission and/or energy storage is made available, and/or if relatively high curtailment factors can be sustained. Research on these issues is ongoing. On the other hand, as discussed above, the good net energy performance of gas-fired electricity is entirely dependent on the condition that the gas be supplied by short-distance pipelines, and not imported as LNG. On the contrary, the coal and

[7] PV is the technology that has the greater potential for further expansion in Chile (Fthenakis et al., 2014).

oil supply chains appear to be intrinsically constrained in terms of the achievable $EROI_{el}$, because of (i) the inevitable investments required for the transport and refining of the feedstock fuels, and (ii) the thermodynamic limits imposed on the fuel-to-electricity conversion efficiency. Finally, while biomass fuels sourced from forestry residues do appear to be a viable alternative, the overall $EROI_{el}$ of this technology is still held back by the comparatively low thermal conversion efficiency at the power plant.

Overall, however, when also considering the point of view of reducing the grid's dependency on non-renewable energy resources, the simultaneous and synergistic deployment of more hydro, wind and PV systems appears to be the most promising strategy for both the SIC and SING grids.

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Why becoming a vegetarian is not going to save the world, *comparing land, energy and water footprints of a Dutch dish with meat and a modern vegetarian one*

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Abstract

Meat production has large impacts on natural resource use, like land and water, contributes to greenhouse gas emissions and causes soil and water pollution. Many studies on sustainable food promote dietary meat reduction. In many developed countries, policy adopts this view. Meat consumption is strongly related to welfare: with increasing income, meat consumption also increases. In developing countries, diets are based on staples, e.g. roots and tubers, and contain little livestock foods. When developing countries show economic progress, food consumption patterns move towards the affluent patterns of developed countries with more livestock foods, like meat and milk, and more other affluent foods, like beverages, sugar and fats. In the last 20 years, emerging economies like China have seen a doubling of meat consumption. Global meat consumption is expected to increase enormously, with huge consequences for resources for food production. Studies that compare the environmental pressure of a portion of meat and a portion of meat substitute conclude that the vegetarian diet is better from an environmental perspective. However, when affluent consumers shift towards a diet with less meat or become a vegetarian, they do not go back to poor people's diets based on staple foods. In general, there is not only a meat replacement, but the whole dish is different, with a large focus on vegetables and nuts. We compared environmental impacts (land, water and energy requirements) of a typical Dutch dish with potatoes, vegetables and meat and a modern vegetarian one with rice, vegetables and nuts. The vegetarian dish puts a far larger claim on natural resources than the Dutch dish with meat, showing that vegetarian dishes do not always lead to environmental pressure decrease. Pressure decreases when consumers return to past menus with large staple fractions. However, modern consumers replace meat with foods with relatively large environmental impacts. Our unexpected outcomes show that meat is not the only dietary environmental problem and that becoming a vegetarian is not the easy way out.

1. Introduction

Today, there is a general consensus that meat consumption has a large impact on the environment. Recent studies have shown the large use of land (Gerbens-Leenes and Nonhebel, 2002; Elferink and Nonhebel, 2007; Kastner and Nonhebel, 2010) and water (Gerbens-Leenes et al., 2013; Ibidhi et al., 2016) related to the production of meat. Next to that, livestock contributes to energy use and carbondioxide emissions and other forms of pollution (Ibidhi et al., 2016; Schanes et al., 2016). It is therefore concluded that in order to avoid environmental pressure, the consumption of meat should go down (Schanes et al., 2016). Studies on the relationship between food consumption patterns in developing countries, characterized by a relatively small consumption of meat, indicate that the use of natural resources is much smaller than resource use of the patterns in affluent countries with large meat consumption (Ibarrola Rivas, 2015). Based on the types of studies mentioned above, to decrease the impact on the environment, in many western countries it is therefore advised to decrease the consumption of meat.

In poor developing countries, small meat consumption is often not a free choice. When people are poor and meat is not available in large quantities or is too expensive, people have no other option than to consume vegetarian dishes (Carnelie and Mariotti, 2017). When affluence goes up, many studies have shown that also meat consumption goes up until some sort of saturation occurs (e.g. Gerbens-Leenes et al., 2010). In the last 20 years, emerging economies like China have seen a doubling of meat consumption (FAO, 2017). In rich developed countries, a vegetarian diet is a free choice and not a result of poverty. This means that in affluent countries, people who make the choice to eat vegetarian dishes, not only eat less meat, but also search for meat replacements. This is an essential difference with people in developing countries who have little meat in their diets. In general, vegetarian diets provide relatively large amounts of cereals, pulses, nuts, fruits and vegetables (Agrawal, 2017). A general trend that is frequently observed in western countries when regular meat eaters move to a diet that includes less meat is the substitution of plant foods, such as legumes, soya foods and meat analogues, nuts and seeds, grains, potatoes, avocados, fruits and vegetables for animal foods (Orlich et al., 2013). Some of these foods have relatively large natural resource use. If in rich developed countries, meat is replaced by other foods, an important question is whether the use of natural resources really goes down. The aim of this research is to analyze the relationship between a shift to vegetarian food patterns in western countries and natural resource use. The research question is: “What is the effect of meat replacement in western menus on natural resource use and what is the difference between natural resource use related to vegetarian diets in developing countries compared to developed countries? In this way, the study extends the existing knowledge related to environmental pressure related to food. Section 2 gives an overview of vegetarian dietary patterns for food consumption, section 3 gives a comparison of the resource use of meat versus plant foods, section 4 gives the results of a case study in which we compare the land, water and energy use of two dishes, a traditional Dutch dish with meat and a typical vegetarian one. Section 4 gives the discussion and section 5 the conclusions.

2. Vegetarian diets and trends in dietary patterns

Vegetarian diets do not include meat and fish. Vegetarianism is often described as the conscious and voluntary choice to exclude meat, fish, seafood, and sometimes dairy and eggs from the diet (Carnelie and Mariotti, 2017). There are different categories of vegetarians. Ovolactovegetarians do not consume meat and fish. Their diets include dairy and eggs. Ovovegetarians also exclude dairy. A vegan diet does not contain any animal foods. Semivegetarians or flexitarians adopt a vegetarian diet of any type, but with the occasional inclusion of animal products, such as meat and fish (Walsh et al., 2017). When people adopt a vegetarian diet and exclude certain foods, there are four different possibilities to adapt the diet: (i) to consume more of the same; (ii) to replace animal foods by plant milks and meat substitutes; (iii) specific culturally supported changes and (iv) adaptations based on personal preferences (Walsh et al., 2017). All categories of vegetarians consume much more legumes, soya foods, nuts and seeds, grains, potatoes, fruits and vegetables than nonvegetarians. If a more sustainable food pattern has been the argument to consume less or no meat, it is important to analyze whether these substitutions really contribute to a more sustainable food pattern. There is a general trend that in developing countries, consumption of livestock foods is small and in western countries consumption is large (FAO, 2017).

Globally, an important trend is that diets of poor people are based on carbohydrate rich staple foods. This is for example the case in Nigeria, where in 2000 150 kg of cereals and 230 kg of starchy roots and tubers were consumed per capita per year. Total consumption of meat was below 10 kg per capita per year (FAO, 2017). When we compare this to the situation in Netherlands in 1990, the Dutch consumption of roots and tubers was only half the amount consumed in Nigeria, whereas the consumption of meat was about eight times larger. When in poor countries incomes increase, people first tend to consume more of the same. When incomes increase further, people buy other foods and replace the staples by more luxurious foods, like meat, processed foods, e.g. beverages, or foods from far, e.g. imported vegetables. There is a linear relationship between incomes and meat consumption until a saturation level is reached (Gerbens-Leenes et al., 2010). There are regional differences among these saturation levels, however, that have to do with cultural differences (Ibarrola Rivas, 2015).

In ancient Europe, vegetarianism was probably uncommon. In the middle ages, several monk orders avoided meat, but not fish, for ascetic reasons. Eating fish instead of meat on Fridays has continued to be a very common Roman Catholic tradition in many parts of the world (Dagnelie and Mariotti, 2017). Today, also sustainability issues become an important reason to stop eating meat or to eat less meat and become a flexitarian. The reason is the low efficiency of animals to convert feed of vegetal origin into meat. It is argued that if humans would consume animal feed, e.g. grains or soya, the food system would become more sustainable. This line of reasoning, however, excludes the fact that animals can also convert feed that is not edible for humans into food, for example residues from agriculture, wastes from the food industry or grass.

3. Case study: comparison meal including meat versus a vegetarian meal

3.1 Introduction case study

Meat production has large impacts on natural resource use, like land and water, contributes to greenhouse gas emissions and causes soil and water pollution. This has to do with livestock feed production. About 5 kg of wheat or soybeans is needed to produce 1 kg of meat. Many studies on sustainable food consumption systems identify meat as a large cause of environmental pressure and promote dietary meat reduction, e.g. by becoming a flexitarier, introducing meatless Mondays or meat replacements by vegetarian substitutes. In many developed countries, policy has adopted this view on the relationship between meat consumption and environmental pressure. Studies that compare the environmental pressure of a portion of meat and a portion of meat substitute conclude that the vegetarian diet is better from an environmental perspective. However, when affluent consumers shift towards a diet with less meat or become a vegetarian, they do not go back to a poor people's diet based on staple foods. In general, there is not only a meat replacement, but the whole dish is different, with a large focus on vegetables and nuts. In this case study, we compared environmental impacts (land, water and energy requirements) of a typical Dutch dish with potatoes, vegetables and meat and a modern vegetarian one including rice, vegetables and nuts.

3.2 Method and data

First, we selected two typical dishes, a vegetarian one and a traditional Dutch dish including meat. The vegetarian dish includes rice, cheese, vegetables produced in greenhouses and nuts, the Dutch dish includes potatoes, cabbage grown in the open air and pork. Table 1 gives the ingredients of the two dishes for four persons.

Table 1. Ingredients of two dishes for four persons, a modern vegetarian dish and a typical Dutch dish with meat

Modern vegetarian dish	Kg	Typical Dutch dish with meat	Kg
Rice	0,30	*potatoes*	1,50
cashew nuts	0,20	*cabbage*	0,60
dried tomatoes	0,10	*sausage (pork)*	0,30
cheese	0,20	*margarine*	0,05
spinach	1.00		
margarine	0,05		

To calculate the environmental impact of the dishes, we calculated the land footprint (LF_{total}), the energy footprint (EF_{total}) and the green plus blue water footprint (WF_{total}). We combined data on dish ingredients (kg) with data on land requirements (m^2/kg), energy requirements (MJ/kg) and water requirements (blue + green water footprints in m^3/kg). The WF_{total} is calculated as:

$$WF_{total} = \sum_{i=a}^{n} i_{a,n} \times (blueWF_i + greenWF_i) \qquad (1)$$

in which *i* is the amount of ingredient a (kg) and WF_i the water footprint per kg of ingredient *i*. For simplicity reasons, we added the blue WF (irrigation water) and green WF (precipitation water), and excluded the grey WF (the WF related to pollution). The energy and land footprints were calculated in the same way. Data on specific energy footprints and on land footprints were taken from Gerbens-Leenes (2000), data on water footprints from Mekonnen and Hoekstra (2010a and 2010b). Table 2 gives the energy (MJ), land (m^2) and water footprints (m^3) per kg dish ingredient.

Table 2. Energy, land and water footprints per dish ingredient for a modern vegetarian and a typical Dutch dish

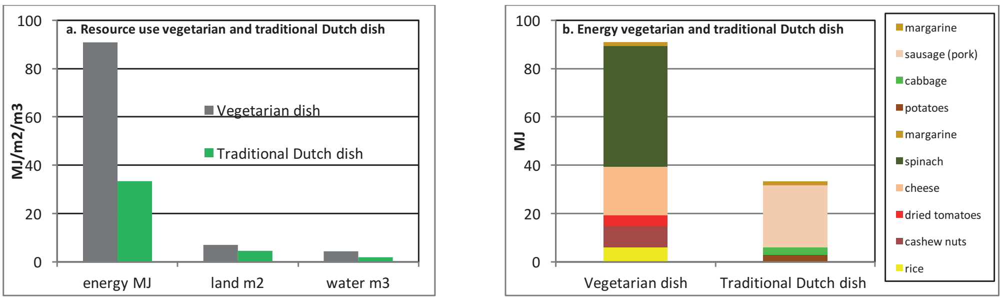
	Energy (MJ/kg)[a]	Land (m^2/kg)[a]	Blue + green water footprint (m^3/kg)
Vegetables (open air)	5	0.2	0.1[b]
Vegetables(greenhouse)	50	0.1	0.1[b]
Vegetables (dried)	43	9	0.8[b]
Bread	18	1.1	0.6[b]
Potatoes	2	0.2	0.1[b]
Rice	20	3	3.0[b]
Margarine	30	10	3.0[b]
Meat beef	110	19	8.0[c]
Meat chicken	86	6	2.0[c]
Meat pork	86	12	5.0[c]
Milk	10	1.3	0.6[c]
Cheese	100	13	6.0[c]
Butter	82	15	6.0[c]
Coffee	38	16	17.0[b]
Nuts	45	10	10.0[b]
Olive oil			12.3[b]
Sunflower oil			6.3[b]

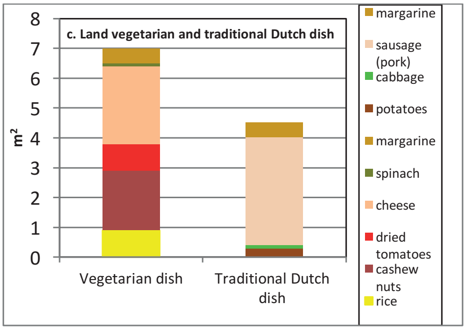
[a.] Gerbens-Leenes, 2000; [b] Mekonnen and Hoekstra, 2010a; [c] Mekonnen and Hoekstra, 2010b

3.3 Results

Figure 1 a-d shows the results of the comparison of the vegetarian dish and the traditional Dutch dish with pork.

Figure 1 a-d. Comparison of the energy, land and water footprints of a modern vegetarian dish and a traditional Dutch dish with pork





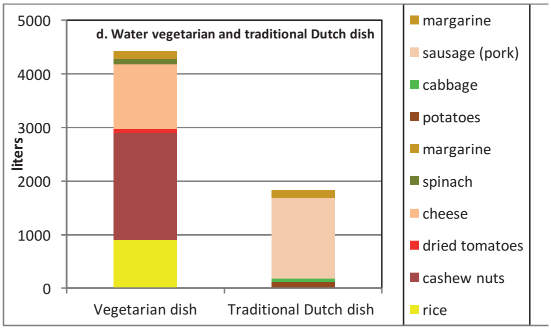


Figure 1a shows that all footprints of the modern vegetarian dish are larger than the footprints of the traditional Dutch dish. Figure 1b shows that the energy footprint of the vegetarian dish is almost three times larger than the energy footprint of the Dutch dish. The main contributors are spinach and cheese. Figure 1c shows that the land footprint of the vegetarian dish is 1.5 times larger than the land footprint of the Dutch dish, with cheese and nuts as the main contributors. The land footprint and also the water footprint of the Dutch dish is dominated by the pork. Figure 1d shows that the water footprint of the vegetarian dish is 2.5 times larger than the water footprint of the Dutch dish. Table 3 gives the results of the footprints per dish ingredient.

Table 3. Energy, land and water footprints of a modern vegetarian dish and a Dutch dish with meat per dish ingredient

	energy (MJ)[a]	land (m^2)	blue + green water footprint (m^3)
Vegetarian dish			
rice	6,0	0,9	0,9
cashew nuts	9,0	2,0	2,0
dried tomatoes	4,3	0,9	0,1
cheese	20,0	2,6	1,2
spinach	50,0	0,1	0,1
margarine	1,5	0,5	0,2
Total	**90,8**	**7,0**	**4,4**
Typical Dutch dish with meat			
potatoes	3,0	0,3	0,1
cabbage	3,0	0,1	0,1
sausage (pork)	25,8	3,6	1,5
margarine	1,5	0,5	0,2
Total	**33,3**	**4,5**	**1,8**

When we compare the footprints of the dish ingredients, we find that the ingredients providing the carbohydrates, rice and potato, show large footprint differences. The energy footprint of rice is two times larger than the energy footprint of potato, the land footprint is three times larger and the water footprint nine times. In the vegetarian dish, spinach has a large contribution to the energy footprint, 50 MJ compared to 3 MJ for the cabbage in the Dutch dish. The spinach is grown in a greenhouse, with large energy use, while the cabbage is coming from the open air. In the vegetarian dish, animal protein is provided by cheese, in the Dutch dish by pork. The footprints of the cheese are slightly smaller than the footprints of pork, but not much. In the vegetarian dish, the cashew nuts have a large contribution to the energy, land and water footprints. The water footprint of the nuts is even larger than the total water footprint of the whole Dutch dish.

4. Discussion

The study showed that the replacement of meat in a vegetarian dish does not necessarily mean that the environmental pressure, expressed here as the use of land, energy and water, goes down. The study of Gerbens-Leenes and Nonhebel (2002) indicated that vegetarian diets based on staple foods, e.g. grains, have substantially smaller land requirements than diets in affluent countries. In this case study we compared two dishes. The vegetarian dish included rice, vegetables from greenhouses, nuts and cheese. The dish with meat included open air vegetables, pork and potatoes. When other ingredients were chosen for the vegetarian dish, e.g. open air vegetables and potatoes, and nuts would have been excluded, the land, energy and water footprints would have been smaller. For the typical Dutch dish, the same line of reasoning is relevant. If we would have chosen greenhouse vegetables or vegetables transported by airplane, e.g. green beans from Uganda, and another meat type, e.g. beef, the resulting footprints would have been larger.

The data on land, energy and water footprints applied for the comparison of the dishes are global average numbers. For specific situations, production might differ, resulting in different numbers. For example, when yield levels are small, e.g. in many developing countries, land requirements and water footprints are large.

The choice of ingredient type is very important for the final results. For example, in a Mediterranean diet, the use of olive oil is very popular. However, olive oil has a much larger water footprint than a broadly applied vegetal oil, sunflower oil. The green water footprint of olive oil is 12,000 l/kg, the blue water footprint 500 l/kg. For sunflower oil, these values are 6000 and 300 l/kg respectively. For meat, the differences among footprint values are also large. In general, beef, for example, has a large water footprint dominated by the green water footprint, whereas pork and poultry have smaller water footprints, but larger blue water footprints. From a water resources perspective, green water (precipitation) causes a smaller environmental pressure than blue water (groundwater and surface water).

5. Conclusions

When in an affluent country, people replace dishes with meat by vegetarian dishes without meat, the environmental pressure, expressed as land, energy and water footprints, not necessarily goes down. This depends on the type of ingredients used for the vegetarian dish. If ingredients are applied with high specific footprints, there is no environmental advantage. The ingredients include, for example: rice, greenhouse vegetables, vegetables transported by plane, nuts, cheese or olive oil. These ingredients are expensive and, with the exception of rice, are generally not included in poor people's diets. Studies that compare the environmental pressure of a portion of meat and a portion of meat substitute conclude that the vegetarian diet is better from an environmental perspective. However, when affluent consumers shift towards a diet with less meat or become a vegetarian, they do not go back to poor people's diets based on staple foods. In general, there is not only a meat replacement, but the whole dish is different, with a large focus on vegetables and nuts.

We compared environmental impacts (land, water and energy requirements) of a typical Dutch dish with potatoes, vegetables and meat and a modern vegetarian one with rice, vegetables and nuts. The vegetarian dish puts a far larger claim on natural resources than the Dutch dish with meat, showing that vegetarian dishes do not always lead to environmental pressure decrease. Pressure decreases when consumers return to past menus with large staple fractions. However, modern consumers replace meat with foods with sometimes large environmental impacts. Our unexpected outcomes show that meat is not the only dietary environmental problem and that becoming a vegetarian is not always the easy way out.

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A multiscale analysis of the EKC for energy use and CO2 emissions

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Abstract

Building on a previous piece of research (Luzzati and Orsini 2009), this paper re-assesses the environmental Kuznets' curve hypothesis (EKC) for total primary energy supply and extends it to CO2 emissions for the period 1971-2014. Two are the peculiar traits of our approach.

1) It performs a robustness exercise by (a) using both parametric and semi-parametric methods, and (b) analyzing different levels, that is, the world as a whole, a panel of 115 countries, some sub-samples of it, and single countries.

2) Consistently with the EKC narrative and with theoretical papers, Energy and CO2 are taken in absolute rather than in per capita terms. The reason is obvious, "Nature cares" about absolute impacts.

Our exercise confirms that also for a time span that includes the great recession, evidence in favour of an Energy and/or CO2 EKC is either absent or a statistical artefact. text

1. Introduction

The environmental Kuznets curve (EKC) debate started in the 1990s and is still very much alive. As well known, the empirical research on the EKC, as well known, gave mixed results. This is explained by the multifaceted nature of the topic. For instance, differences are observed between global and local pressures, being the latter more easily made subject to regulation. However, the mixed evidence is also due to the variety of research strategies. Actually, criticism has often been levelled at the scant attention paid to robustness (e.g. Stern, 2004). Several facets of robustness have been investigated, for instance by applying non-parametric methods (e.g. Bertinelli and Strobl, 2005; Azomahou et al., 2006), by comparing alternative datasets and different parametric setups (Galeotti et al., 2006a), and by testing for series stationarity (Galeotti et al., 2006b). The robustness exercise presented here involves both comparisons between parametric and non-parametric methods, and the validation of cross-country findings by looking at other levels of analysis (i.e. the world as a single country and individual countries). This should mitigate the risk of statistical artefacts arising from pooling heterogeneous country patterns.

As shown in Luzzati and Orsini (2009), strict adherence to the original EKC narrative involves two differences with the usual practice in the empirical EKC literature, namely, taking emissions in absolute rather than per capita terms, and not adding any other control variable. The first feature derives from the definition of the EKC hypothesis, according to which "higher levels of development [… will] result in levelling off and gradual decline of environmental degradation" (Panayotou, 1993, 1). Actually, also theoretical contributions model environmental degradation in absolute terms, which is, by the way, consistent with the fact that 'Nature' is affected by total human pressure, and not per capita. The second feature, that is, investigating a reduced form in which per capita income is taken as the only 'explanatory' variable (Azomahou et al. 2006, 1348), also derives from the EKC original idea which was about exploring the relationship between income and environmental degradation rather than looking for the anthropogenic drivers, which would entail modelling the structural linkages explicitly.

The present exercise applied the above described research strategy to total primary energy supply (TPES) and carbon dioxide (CO2) emissions. The availability of long time series, which cover also the strengthening of globalization and the great recession, allows to assess whether some evidence of inverted-U patterns has emerged in the last decade and whether some countries have been effective in reducing their energy consumption and CO2 emissions.

Although CO2 is also analyzed, the main focus remains energy consumption, from which ultimately arise human pressures to the environment.

Section 2 describes the dataset, section 3 report the analyses at the world level, section 4 at the panel level, section 5 reports country patterns, section 6 concludes.

2. The dataset

In its "CO2 Highlights", the International Energy Agency makes freely available online some statistics for Energy and Co2 emissions for 145 countries and other regional aggregates, with time series starting from 1971. IEA includes also the series for income and population. After some adjustments in order to get a balanced panel, we ended up with 115 countries. Figure 1 gives a snapshot of the dataset, showing on the x-axis per capita income and on the y-axis respectively total primary energy supply and CO2. For a better visualization, values are in natural logarithms. We took GDP in PPP[1] (expressed in thousand dollars) due to the cross-country nature of the analysis. Total primary energy supply is expressed in PJoules and CO2 emissions in million tonnes.

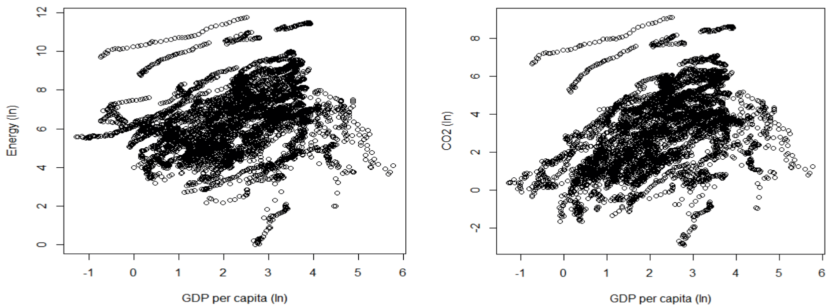

Figure 1. A snapshot of the dataset: Energy and CO2 vs Income p.c.

[1] PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States. The IEA 2016 dataset refers to GDP in 2010 US$. For details see the technical notes of the IEA (2016, p. 141)

A preliminary analysis of the data shows that at least 13 them have to be considered as outliers, that is, countries whose patterns cannot be mimicked by the other countries. They include small or very small peculiar countries, most of which show disproportionately high energy-consumption and large revenues from oil exports[2].

3. The world pattern

Investigating the EKC hypothesis at the world level allows neutralizing the effects of two countervailing forces - namely the transfer of cleaner technologies and the "environmental displacement" (pollution have hypothesis) between rich and poor countries - that are considered crucial since the beginning of the EKC debate (Grossman and Krueger, 1991). The scatter plots (Figure 4) suggest that an inverted-U relationship is not plausible. This is confirmed by the co-integration analysis which is reported below.

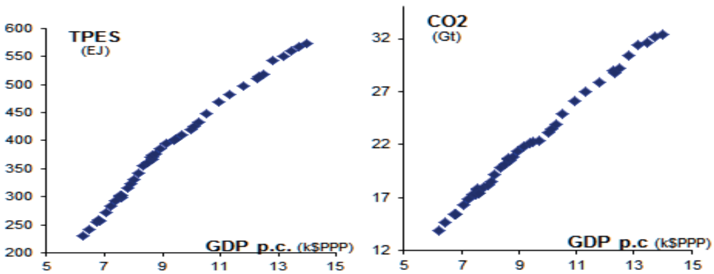

Figure 4. The Energy-GDPpc and CO2-GDPpc relationships at the world level.

Since the augmented Dick-Fueller test shows that all series are integrated of order 1, we looked for cointegrating relationships. The following are best fit of the data we could find

$$Energy = 1.434GDPpc + D9114(0.433GDPpc - 0.199GDPpc^2) + 9.726 - 0.012D7384 - 0.016D9802 - 0.014D0708 \quad \text{(eq.1)}$$

n=44, ADF(6) regression: $\tau_{nc} = -5.387$, $p<0.01$ (MacKinnon, 1996)

$$CO2 = 1.264GDPpc + D9114(0.246GDPpc - 0.113GDPpc^2) + 7.205 + 0.025D7180 - 0.025D9802 - 0.010D0709 \quad \text{(eq. 2)}$$

n=44, ADF(3) regression $\tau_{nc} = -4.695$ $p<0.01$ (MacKinnon, 1996)

Variables are in natural logarithms. "Dxxyy" are intercept dummies going from year 'xx' to year 'yy'

Both CO2 and Energy show a linear relationship with per capita income until 1990 and slightly concave after, which is consistent with the break-up of communist regimes in Eastern Europe. The intercepts became temporarily lower between 1998 and 2002, when the CO2 energy content reached its minimum, and around the great recession. Also the oil shocks of the 1970s significantly reduced primary energy, while the opposite occurred for CO2 because of the abovementioned predominance of oil and coal in that period. The elasticities are bigger than one, that is, energy and CO2 emissions increases more than proportionally with income.

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[2] Iceland, Luxembourg, Brunei Darussalam, Curaçao /Netherland Antilles, Trinidad and Tobago, Bahrain, Kuwait, Qatar, United Arab Emirates, Gabon, Oman, Libya, Saudi Arabia.

4. A Panel data analysis

4.1 Methods

To avoid forcing data into a specific frame, we started from a semi-parametric and fit the data with a Generalized Additive Model, using the routines of the MGCV package for R (Wood 2006). Since standard diagnostics do not apply, the package provides estimated Bayesian confidence intervals.

We then moved to the parametric estimates, for which we used a cubic specification

$\ln Y_{it} = \alpha_i + \beta_1 (\ln GDP/P)_{it} + \beta_2 (\ln GDP/P)^2_{it} + \beta_3 (\ln GDP/P)^3_{it} + \varepsilon_{it}$

where Y is either Total Energy or Total CO2 emissions

The Hausman test suggested specifying α_i as fixed effects. The presence both of first order autocorrelation and of heteroskedasticity emerged when performing respectively the test discussed in Wooldridge (2002, 282) and the likelihood ratio test. Thus, we fit our model by using feasible generalized least squares (FGLS). Series stationarity was checked by using the tests developed by Levin, Lin and Chu (2002) and by Im, Pesaran and Shin (2003).

Parametric estimates were specified both for the dataset as a whole (excluding outliers) and for countries grouped according to their highest income per capita over the period.

4.2 Results

The semiparametric estimates (see Figure 2) show that there is no evidence for an inverted-U shape neither for energy nor CO2 emissions. For the latter, however, the curve becomes less steep for high levels of income.

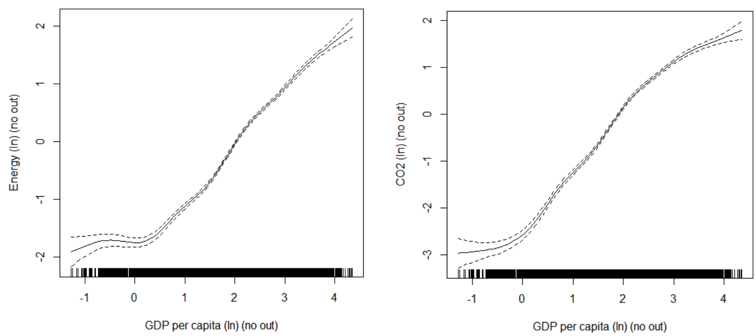

Figure 2: TPES vs GDPPC and CO2 vs GDPpc: semi-parametric regression without outlier and confidence band (5%).

In the EKC literature, a time trend is often included in the regression. In our case, adding a time trend gives an inverted-U shape. However, the (significant) coefficient for time is positive, contradicting the idea that technological progress reduces energy and emissions. EKC shapes emerge also when outliers are included.

The parametric estimation (cubic specification) without outliers, both for all countries and for the countries pooled by income groups, confirmed what is visually shown by the semi-parametric regressions. Only for CO2 a possible EKC pattern emerges, for very high level of income[3] (and emissions), as shown by table 1. All other results are available in the full paper.

Table 1: Parametric estimate (FGLS) of the CO2-EKC

	Coeff.	*Std. Error*	*p*
ln GDP p.c.	0.2855	0.112	0.011
(ln GDP p.c.)^2	0.5989	0.074	0.000
(ln GDP p.c.)^3	-0.1104	0.014	0.000
Constant	1.1265	0.070	0.000
n=102	turning point ≈ 46,630 $2010 PPP		

5. Country level analysis

As shown in the full version of the paper, we have analyzed individually the countries of our panel to verify whether any inverted-U pattern emerges at the country level. To this purpose, we analysed the scatter plots comparing GDP pc with, respectively, total TPES and total CO2 emissions. By obtaining seven clusters of countries, we could apply an appropriate scaling that ensured full comparability among countries, avoiding misleading interpretations of the results.

Three major results emerge from our analysis. First, it is possible to observe some "recurring" patterns, which are largely inconsistent with an inverted-U shape. In particular, most countries show a (more or less) steep increasing relationship between TPES or CO2 and GDP pc. On the other side, others show "non-linear" relationships between the two variables: this is especially the case of very small or oil-based countries.

Second, the extension of the series to the period involving the Great Recession (2009-2014) had a relevant impact on countries behaviors. Indeed, for some of them we observe that for the same level of TPES or CO2 emissions, GDP pc has stopped growing (e.g., Japan and Belgium) or has even reduced (e.g., Spain) generating a scatter plot that, for the most recent observations, is inconsistent with the standard EKC narrative.

Third, for some countries, TPES and CO2 emissions seem rather stable and are associated, despite the crisis, with a GDP pc increase (e.g., United Kingdom and Sweden). In other words, even though TPES or CO2 are not yet declining in the presence of a GDP pc growth, these countries are now emerging as potential candidates for the future presence of an EKC.

To conclude, a special comment should be provided for Germany. Indeed, this is the only country in the panel for which an EKC seems to be already emerged, since in recent years Germany has experienced a reduction in TPES and CO2 emissions levels (after reaching higher levels in previous years), associated to a constant GDP pc growth despite the Great Recession. The hypothesis we will test behind this result is whether the highest levels achieved in Germany could be considered as a "physiological" roof beyond which other countries with similar geographical and industrial features (e.g., France, UK and Italy) will not be able to go. This test would

[3] The average per capita income by countries of each group are as follows: High income =27908, medium income 9724, and low income 3,085.

allow us to forecast a future EKC behavior also for those countries, as it appeared for Germany.

6. Conclusive remarks

This paper is an investigation on the Environmental Kuznet Curve for energy and CO2 emissions. This is partially an update of a previous paper (Luzzati and Orsini, 2009). The availability of data for a much longer time span (a decade) makes the analysis interesting, especially in the light of both the development of emerging countries as China and the Great recession.

We performed a robustness analysis, using both parametric and semi-parametric methods, and analyzing the data at the global level, as a cross-country/time-series panel, and at the single countries level.

At the global level, the co-integrated relationship between GDP per capita and, respectively, absolute energy consumption and CO2 emissions is linear and positive until 1990 when a structural break - consistent with the dissolution of the Soviet Union – occurs and remains positive thereafter, though becoming slightly concave.

The panel data analysis shows that there is no evidence for an EKC-shape, both for Energy and CO2. An inverted-U emerges only when including the outliers or a time trend. Both of these inclusions, however, appear as very questionable.

The analysis at the country level helps in understanding why the EKC-shape does not emerge in the panel data analysis. Actually, some recurring patterns emerges. In most cases, for both the ECK investigated here (energy and CO2), countries show either a linear increasing relationships, or a "non-linear" relationship in case of countries affected by wars or economically strongly dependent on raw material. The country analysis also shows that some countries affected by the great recession, mainly in Europe, the level of energy and CO2 has actually diminished more that income reduction. In any case, only Germany has trend following the common EKC narrative, while other few "developed" countries show recent trends of some stabilization in the levels of energy and CO2.

To conclude, the analysis showed that both for energy and CO2 any evidence for EKC is either absent or a statistical artifact. Such a result emerged from a large dataset (more than 100 countries) that covers a time span of 44 years, that is, including also big changes, such as the increase in globalization processes, the emergence of developing countries as China, and the Great Recession.

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Data-driven Building Archetype Generation for Urban Building Energy Modelling

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Abstract

Energy retrofitting of existing buildings is a basic approach for reducing primary energy and greenhouse gas (GHG) emissions in cities. Development of urban intervention policies requires efficient and accurate tools for comprehensive analysis of building energy performance on city scale. Urban building energy modelling (UBEM) is a hybrid modelling approach that unites statistical top-down and physical bottom-up models, providing the necessary trade-off between accuracy and coverage of simulations. Building energy models are automatically generated by representing building stock as different 'building archetypes' — sample or virtual buildings that characterise subsets of buildings of the same kind. Using building archetypes is an efficient way to describe the current state of building stock, but does not automatically create backward connectivity between the archetype building and buildings constituting the archetype, which is essential for the operational potential of UBEM, e.g. analysis of available energy-saving measures.

This paper presents a new approach to building archetype generation using physics-based characterisation models and demonstrates this approach for the case of Stockholm. Three building archetypes for 3808 buildings were constructed using energy signature models and building energy simulation tools. The proposed approach allows inclusion of the variability within each building archetype subset and validation of building energy simulation models obtained against measured data on factual heat energy use, enabling better UBEM quality and, ultimately, more grounded retrofitting decisions.

1. Introduction

Energy conservation in the existing building stock is the cornerstone for reducing primary energy consumption and greenhouse gas (GHG) emissions in cities (EBC, 2014). In order to meet ambitious energy efficiency and climate mitigation targets, cities need to understand current energy demand and future effects of various retrofitting decisions. The conventional energy models currently used for decision-making support are either limited in detail (top-down) or too exhaustive to be applied on a large scale (bottom-up) (Swan and Ugursal, 2009). However, emerging urban building energy models (UBEMs) use growing volumes of urban energy data and significantly reduce the amount of effort needed from human modellers (Reinhart and Cerezo Davila, 2016). UBEMs provide automated generation of building energy models through abstraction of building stock by different 'building archetypes' — sample or virtual buildings that characterise subsets of buildings of the same kind (Cerezo Davila et al., 2016). However, substitution of the whole archetype building subset by a single building induces a risk of the oversimplification resulting in poor quality of the modelling output. Availability of rich datasets on factual heat energy use open the way for a new approach to generating building archetype subsets through characterisation of the city building stock with energy signature models.

This paper describes a novel method for building archetype generation and demonstrates the method for the case of Stockholm.

2. Background

Rapid development of computing and sensor technologies has created a 'big data' challenge to running building energy simulations in a conventional way, which calls for new approaches for handling and utilising the data (Sanyal and New, 2014). UBEM has emerged in recent years as an efficient hybrid of top-down statistical and bottom-up engineering approaches (Kavgic et al., 2010; Swan and Ugursal, 2009) and is expected to become a main planning tool for energy utilities, municipalities, urban planners etc. (Reinhart and Cerezo Davila, 2016).

Creation of city-wide models requires the synthesis of many models with similar characteristics, which is not possible to do manually. Therefore, UBEMs utilise building archetypes, an approach that provides a compromise between accuracy and speed of simulations (Li et al., 2015). It has been extensively used in the context of national and regional bottom-up building stock models to analyse the current state of building stock and the aggregated impact of energy efficiency policies or new technologies (Ballarini et al., 2011; Lauster et al., 2016; Mata et al., 2014).

The UBEM developed in the present study combines energy signatures and building energy simulations created in DesignBuilder. Energy signature is a reduced-order physics-based (engineering) regression model which is simple, requiring only energy use data, and supports comparability across large numbers of dwellings (Swan and Ugursal, 2009). DesignBuilder is an interactive interface for the energy simulation program EnergyPlus used for modelling building heating, cooling, lighting, ventilating, and other energy flows (Clément, 2012). Calibrated engineering models combined with building energy simulations tools are have been praised for "reliable simulations of options to investigate their energy savings and emissions reduction potential" (Fumo, 2014, p. 59).

3. Method

The proposed method to building archetype generation utilises data from four data sources:

1. M**etadata** on the building stock are used for building stock segmentation and setting up virtual archetype building energy simulation models. In the demonstration case, these metadata were extracted from the Energy Performance Certificates (EPC) dataset obtained from the Board of Housing, Building and Planning (Boverket). This EPC dataset covered 15 947 buildings in Stockholm[1] and contained information on building type, construction year,

[1] Stockholm municipality is referred to hereafter as "Stockholm".

floor area, envelope form, energy use per source, energy system installations etc.

2. **Measured** data on factual heating energy consumption (hereafter FDH) are used for creating characterisation models for each building analysed. The measured data for the case were extracted from the district heating hourly metering dataset obtained from the local energy utility AB Fortum Värme Samägt med Stockholms Stad. The FDH data covered 15 068 metering points in the year 2012 with hourly precision representing all customers of the local district heating network, which corresponds to about 85% of the total building stock in the city. The data also contained information on type of building usage, building age category and total heated area (A_{temp}).
3. **Reference** data on user indata and the building envelope information are used for setting up virtual archetype building energy simulation models. Here the reference data were obtained from the Sveby project (SVEBY, 2012) and the “Så byggdes husen” book (Björk et al., 2013).
4. **Climate** data on the ambient temperature. Relevant data for the Stockholm case were extracted from the Swedish Meteorological and Hydrological Institute (SMHI)[2] data portal. Time series for 2012 and the period 1981-2010 with hourly precision were used for characterisation of the building stock with energy signature models.

The *metadata* and *measured* datasets are linked through matching cadastral codes. Buildings that fail to link are removed from the analysis. Moreover, the EPC and FDH data are regarded as components of a single linked dataset.

N target building archetypes are defined by subset criteria for the building features in the *metadata*. The dataset is segmented according to the archetype definitions into the N subsets $archetype_i$. Each subset is analysed for outliers, which are removed in the case of low confidence ($p < 0.01$).

Each building is characterised by the **energy signature** $ES = (\theta, c, \beta)$ (see Fig. 1) obtained from fitting the specific heat power $P_{heat}\,(q)$ calculated from the *measured* data with the following quasilinear regression model:

$$P_{heat}\,(q) = \begin{cases} c + \beta\,(\theta - q), q < \theta \\ c, q \geq \theta \end{cases} \quad (1)$$

where q is ambient temperature, θ is balance point temperature, c is base load (domestic hot water consumption) and β is energy performance coefficient.

[2] http://smhi.se

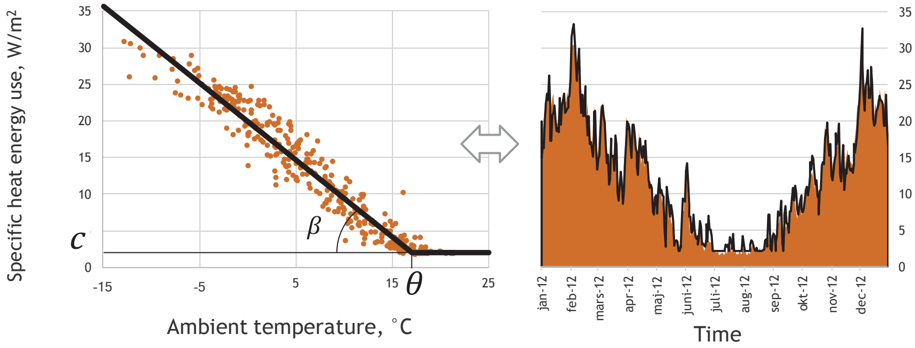

Fig. 1. Example of (left) the energy signature of a building and (right) specific heat energy use by time. Measured and modelled values are coloured orange and black, respectively.

Secondary outlier analysis is performed for energy signature parameters θ, c, β.

The virtual archetype building for each of the target archetypes is constructed using the weight averaging of the corresponding archetype subset data by A_{temp}:

$$feature_{archetype_i} = \sum_{\forall building \in archetype_i} \frac{feature_{building}}{A_{temp_{building}}}, \; i = 1..N \qquad (2)$$

A building energy simulation model is created for each building archetype in the computer simulation tool DesignBuilder. The model is set up with the *reference* data and then modified according to the aggregated building features from (2). The simulation model obtained is then calibrated against the energy signature for the archetype building $ES_{archetype_i}$ that is derived from the buildings of the $archetype_i$ using (2).

The constructed building archetype model is a baseline model that can be updated for modelling various building modifications, i.e. energy retrofitting, and then scaled back to obtain the updated energy signature for each building in the subset $archetype_i$, as exemplified for the balance point temperature parameter:

$$\theta^*_{building} = \frac{\theta^*_{archetype_i}}{\theta_{archetype_i}} \cdot \theta_{building} \qquad \forall building \in archetype_i, i = 1..N, \qquad (3)$$

where $\theta_{archetype_i}$ and $\theta_{building}$ are, respectively, baseline balance point temperature of the virtual archetype building and the modelled building; and $\theta^*_{archetype_i}$ and $\theta^*_{building}$ are, respectively, estimated balance point temperature of the virtual archetype building and the modelled building after retrofitting measures.

4. Results

The analysis was performed within the scope of an E2B2 project aimed at development of a data-driven strategic planning framework for cost-efficient building energy retrofitting in Stockholm. For the purposes of the present analysis, three building archetypes (A1-A3) were selected (Table 1), based on a) high share in the whole city building stock, and b) relative homogeneity of the building sets represented by these archetypes. The subset criteria defined and descriptive statistics for the archetype subsets after data cleaning are presented in Table 1.

Table 1: Summary of the three selected building archetypes A1-A3

Code	**Description**	**Subset criteria**	N, number of metering points	$\sum A_{temp}$, total heated area, mln m^2
A1	Residential 1946 - 1975	*Building category = 1.1-1.5*[3] *or 2.1-2.5*[4] *Construction period = 1946-1975*	2402	14.18
A2	Offices	*Building category = 6.1-6.5*[5] *or 7.1-7.4*[6]	1280	12.13
A3	Residential 2006 - …	*Building category = 1.1-1.5 or 2.1-2.5* *Construction period = 2006-…*	126	0.84

A total of 3808 energy signature models were created by fitting the regression model (1) to the *metered* data. The total deviation between the *measured* and *modelled* values was less than 1.2%. The modelling results across the balance point temperature θ and the energy performance coefficient β for the three archetypes are presented in Fig. 2.

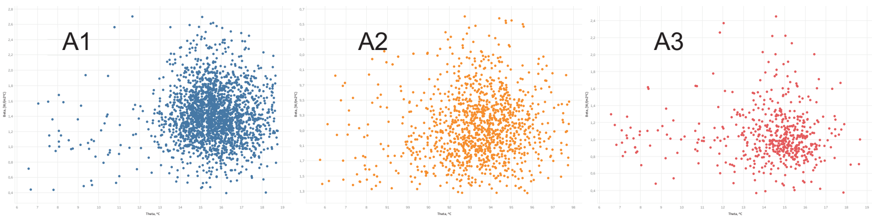

Fig. 2. Distribution of the balance point temperature θ (horizontal) and the energy performance coefficient β (vertical) for the constructed archetypes A1 (residential buildings 1946-1975), A2 (office buildings) and A3 (residential buildings 2006-…).

As can be seen, Fig. 2 supports the assumption that the selected archetypes are distributed homogeneously. Splitting archetype A2 (office buildings) by building age period did not reveal any significant influence of construction year on building energy performance, which confirms conventionally reported observations by building energy experts.

Virtual archetype buildings were created from the *reference* data and aggregated features of the buildings from each archetype subset according to (2). Energy signature characteristics used for the model calibration are given in Table 2.

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[3]Hereafter, building categorisation of the FDH dataset is used. Categories 1.1-1.5 stand for *“Residential building in housing estate” (“Bostadshus i kvartersbebyggelse”* in Swedish)
[4]Categories 2.1-2.5 stand for *“Residential detached” (“Bostadshus friliggande”* in Swedish)
[5]Categories 6.1-7.5 stand for *“Office and retail properties” (“Kontors- och butiksfastigheter”* in Swedish)
[6]Categories 7.1-7.4 stand for *“Office building with other activities” (“Kontorshus med annan verksamhet”* in Swedish)

Table 2: Aggregated energy signature characteristics of the building archetypes constructed

Code	Description	A_{temp}, heated area, m^2	θ, balance temperature, °C	c, base load, W/m^2	β, performance coefficient, W/m^2°C
A1	Residential 1946 - 1975	5 903	15.34	4.46	1.32
A2	Offices	9 477	13.42	1.40	1.08
A3	Residential 2006 - …	6 632	13.84	2.79	0.90

The baseline models for the constructed building archetypes were then updated to enable modelling of different energy retrofitting solutions in the buildings of a particular archetype. Finally, the scaling technique (3) was applied to modelling of the updated energy performance of each building in the selected archetype subsets, in order to improve the overall quality of the UBEM developed.

5. Discussion and Conclusions

Our novel approach to building archetype generation involves applying statistical methods to building data and exploits the energy signature method for characterisation of the building stock, in order to maximise the use of available information for each individual building. The method was tested on Stockholm's building stock and further validated with data on factual heat energy use.

The constructed archetypes allow the modeller to: a) establish quality control for constructed models, b) develop different energy-saving measures for buildings in each archetype subset and c) obtain more precise estimates of energy savings for city-wide energy retrofitting compared with a 'one-type-fits-all' solution applied previously for the case of Stockholm (Shahrokni et al., 2014).

It is worth mentioning that while the building archetype approach allows the energy performance of the building stock on city level to be simulated in a time- and cost-efficient way (Cerezo Davila et al., 2016), the conventional segmentation of the building stock by nomenclature (construction year, energy demand, building type and shape etc.) has a number of pitfalls. For example, a) number and content of building archetypes depend purely on the expert knowledge of the modeller and can be insufficient or redundant; b) all remaining building attributes are neglected in favour of those selected, leaving a significant part of the variance unexplained; and c) there is a risk of inaccurate building classification due to random errors in the building attribute data. These deficiencies may lead to low quality of building archetypes and, consequently, should be addressed in future studies.

In conclusion, the proposed approach makes it possible to consider variability within each building archetype subset and to validate the building energy simulation models obtained against measured data on factual heat energy use, enabling better UBEM quality and, ultimately, more grounded retrofitting decisions.

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Sustainability of the value chains of forest bio-economy and the added energy

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Abstract

The paper considers the value added to products made of wood in terms of energy required for production of merchandises within a forest-based value chain. The total amount of energy added to the basic energy content of the original wooden resource of biomass is applied to derive an indicator of the production sustainability with respect to emissions from energy consumption and the storage of CO_2 isolated by photosynthesis. Attention is paid to limitations of CO_2-neutrality of wood fuels and to indices reflecting the natural value added in terms of energy and emergy contents of a commodity of the value chain being assessed.

Keywords: forest bio-economy, value chains, added energy, limits to sustainable growth, CO_2-neutrality, CO_2 storage, emergy.

1. Introduction

Since 1990-ies the hype of resolving the contradictions between the economic activity of humans and ecological sustainability the concept of bio-economy has condensed into national and international agendas and programmes to change the business as usual on a global scale by technological innovation (Enriquez, 2002; OECD, 2005; OECD. 2009; see also[1] The Bioeconomy Report 2016).

Meanwhile two contradictive visions (paradigms) of a bio-based economy (*bio-economy* for short) have emerged and been discussed by a number of authors (Kitchen, 2011; McCormick, 2013; Levidow, 2015) the one of which developed from techonomics (Enriquez, 2002) has become established as the mainstream model of future technological progress within the framework of the present profit-driven market economy (OECD, 2005; Aguilar, 2009). The practice of replacing coal by wood for generating electricity in power stations under assumptions of CO_2 emissions neutrality of wood as granted has been strongly criticised and shown to have bad scientific background (Brewer, 2007; Econexus, 2007; Greenpeace, 2011; Schulze, 2012; Paul, 2013; Upton, 2015). Conditions of CO_2-neutrality of burning wood fuel are limited by requirements of sustainability (Abolins, 2016).

The bio-economics in the existing profit-driven market economy is expected to expand the resource basis for further unlimited economic growth through innovation of high value added competitive products[2]. The beneficiaries of high value added commodities of the downstream value chains are investors and other stakeholders profiting from it, not the general public, eventual users, nor the ecological sustainability. In a financialised economy (Fieldman, 2014) environmental concerns are obscured by

[1] http://www.era-platform.eu/files/7114/9847/3625/JRC_Bioeconomy_Report2016_FINAL_web.pdf

[2] https://data.oecd.org/natincome/value-added-by-activity.htm

fiscal terminology and belief that economy is driven by money while in the physical reality it is driven by energy.

The considerations presented henceforth attempt to find criteria for sustainability of wood bio-economy value chains in terms of energy consumed on producing commodities downstream a value chain.

2. Results and discussion.

With account for sustainability the forest, and produced commodities down the value chains are carbon deposits. Hence, as long as the energy added to a value chain does not exceed the initial energy content of the input biomass the chain (and the product) can be regarded as sustainable with respect to climate in the sense that the carbon equivalent of the energy added does not exceed that of the deposited in the products.

The added energy index defined as the ratio:

$$I_{AE} = \frac{E_a}{E_o + E_a} \tag{1}$$

where E_o – content of energy originally present in wood to be processed; E_a – energy added (consumed) in the process of production of the commodity can be used for assessment of sustainability of a value chain.

By introducing dimensionless energy scale in units of E_o equation (1) is rewritten as:

$$I_{AE} = \frac{E_i}{1 + E_i} \tag{2}$$

where $E_i = \frac{E_a}{Eo}$.

Sustainability (index) of the value chain can be derived from equation (2) as the difference between its maximum value 1 corresponding to E_i= 0 and the added energy index of a particular commodity or the sum of the total energy consumed along the whole value chain:

$$S_i = 1 - I_{AE} = 1 - \frac{E_i}{1 + E_i} = \frac{1}{1 + E_i} \tag{3}$$

The indices posed by equations (2) and (3) are presented in Fig. 1 as functions of the added energy in units of E_0. The critical values of the indices equal to 0.25, 0.50 and 0.75 can be accepted as low, medium and high. The index of sustainability is defined to save the energy consumed to produce commodities in the value chain; therefore, a high value of energy added is not a benefit unless making **profit** from draining the scarce, limited real source driving the economic system.

Another aspect of the value chains from forest bio-economy concerns the biomass feedstock of a particular chain after logging the timber for instance, paper pulping, bio-refinery, bioenergy require crushing as a pre-treatment to separate and extract the components for further treatment. Since solid wood is the most valuable limited material while plenty of other lignocellulosic residues (from agriculture and forestry) is available, it is rational to save timber for construction materials as a long-term carbon deposit. The crushed feedstock of value chains (pulping, bio-refinery, fuel, composite materials, etc.) can be interchanged by adapting for the purpose available local resources.

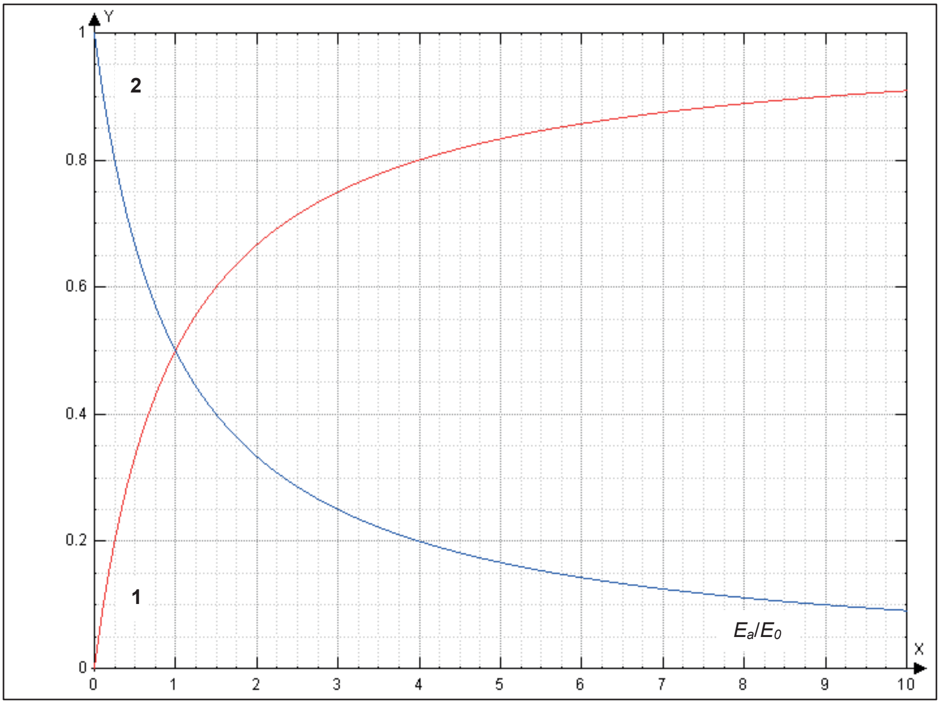

Fig. 1. Added energy index, equation (1) – **1**, and sustainability index, equation (2) - **2**, as functions of added energy.

Of course, the energy added to produce a commodity, contributes to the overall value of the item and is included in the fiscal expression of the value added along with profit. However, the real value of a product is determined by the emergy content of it. For that reason, to assess the total value of the product, the value of the energy added should be converted to emergy in accordance to the particular sources having been employed and dependent on the particular case. The amount of added emergy depends on the kind of energy consumed. A particular value chain is bioenergy consuming any kind of lignocellulosic feedstock the main concern being CO_2-neutrality. On the global scale

CO_2-neutrality of burning wood is strongly limited by requirements of ecological sustainability. The critical values of the indices are intended to estimate the trends of energy consumed on a commodity in the value chain.

3. Conclusions

The indices are designed to provide a quick oversight of energy consumed on commodities and in the whole value chain.

The critical indices are defined to reach the value of 0.5 at added energy being equal to E_0 – the energy content of the initial feedstock.

Priority of solid wood feedstock should be granted to value chains of large-scale products.

Conditions of sustainable harvesting for forest bioenergy include replanting the annual forest felling area to absorb the annual released amount of carbon.

Acknowledgements

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Improvement of Gray Water Footprint Calculation Method Based on Comprehensive Evaluation

Hui Li, Gengyuan Liu, Zhifeng Yang, Marco Casazza and Biagio F. Giannetti

The Gray Water Footprint (GWF) analysis method, defined as the volume of fresh water required to assimilate the load of pollutants discharged into water based on natural background concentrations and existing ambient water quality standards, has been widely used in regional water quality management. In traditional calculation method, GWF value is obtained by dividing the load of critical pollutant by the difference between the ambient water quality standard for that pollutant and its natural background concentration in the receiving water body. In other words, GWF refers to the volume of freshwater that is always only required to assimilate the load of the largest concentration of pollutants based on existing ambient water quality standards. However, many studies have raised questions about this traditional single factor evaluation method, since it lacks the consideration to the combined effects of multiple pollutants, which will lead a higher GWF result in confidence-limit rate. In this study, a new GWF calculation framework oriented the solutions of multi-pollutants is proposed based on a 2-phases calibration model. In the first phases, we consider the dilution and auto-purification process of multi-pollutants in natural waters. In the second phases, several comprehensive evaluation methods, such as the fuzzy synthetic evaluation (FSE), principal component analysis (PCA) and fuzzy inference system (FIS), are applied to determine the “ecological threshold” of GWF. The application conditions and uncertainties of the three multi-factors appraisal methods have also been discussed. Our research gives the methodological support for the precise calculation of GWF.

Sharing Spaces in the Sharing Economy – to save energy, increase well-being or boost innovation? How do new initiatives align with energy transition?

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Abstract
Our paper is informed by the recent interest in how the sharing economy and related initiatives may act as drivers for energy transition and increase well-being and social sustainability in smart sustainable city contexts. We take the example of temporary buildings that for a limited time period offer shared public spaces for public events in the city. Such initiatives are often linked to quadruple helix initiatives in which a local city council, industry and academia join forces to engage citizens in the energy and climate debate, with a temporary building structure as the focal point. The paper argues that such energy initiatives are valuable in terms of social sustainability since they create additional public space for the benefit of citizen debate; contribute scalable solutions and effective infrastructure that can promote energy awareness among citizens. However, there is limited scientific evidence, and a lacking awareness, of the energy efficiency and climate comfort relating to temporary buildings for public use. Our preliminary results show that such factors risk to obscure the well-intended objectives of quadruple helix initiatives to support energy transition. The revealed problems of a Stockholm use case suggest that in spite of significant social and economic impact resulting from curated public events which attracted an unprecedented number of visitors, energy consumption, climate comfort and indoor air quality are nevertheless important factors that also must be considered in the design and implementation of temporary building structures. The paper concludes that better climate control strategies and an integration of *energy efficiency* and *shared economy thinking* is necessary at the earliest stage of a planning process, for temporary buildings to be successful.

1. Introduction

1.1 Sharing spaces in the sharing economy

The sharing economy has been ramping up across Europe in the last couple of years, characterised by a wide spectrum of innovative end-user services, each with a customized ICT-platform as its commercial basis. So far, the greatest market potential is found in segments that have created added value from the existing building-stock and infrastructure, namely *peer-to-peer accommodation, peer-to-peer transportation, on-demand household services, professional services* and *collaborative finance.* These five sectors have generated total revenues of €3.6bn and facilitated €28bn of transactions in 2015 only, hereby confirming that the sharing economy activity across Europe is now in full acceleration and is expected it to reach additional market segments (Vaughan & Daverio 2016). The sustainable transformation of cities is a vital condition for the turn-around to a zero-emission society, and sharing services offer the potential to reduce energy consumption, not only by a more effective use of the built and already heated spaces, but also by fostering new sustainable patterns of behavior among citizens. Digitalisation is overall considered as a key enabler for the process of energy transition[1] and in this respect, the existing building-stock is an important asset in the aim to meet climate and energy commitments, with a potential to *reduce* energy consumption, ranging from 15-40% (Nguyen & Aiello 2013). In consequence, it will be possible to evaluate the effects of the sharing economy on the energy use of our existing building-stock. Will

[1] UN Habitat 2016, 2017 and UNEP 2015 https://unhabitat.org/

heated flats be more effectively shared? Or will new services offer such easy access to sharing spaces and sharing goods that transport and delivery will increase, hence with a negative environmental impact?

Beyond a more effective use of the existing infrastructure, the sharing economy can facilitate sharing spaces and services in the public realm. To date, bottom-up initiatives dominate the sharing economy market, with citizens as its main entrepreneurs, consumers and enablers, but this is expected to change. The point of departure for our research is that the sharing economy creates new opportunities for cities and other stakeholders, fully in line with the overarching aims to plan smart sustainable cities. On the premise that community-building, citizen collaboration and user empowerment are important measures for the necessary energy transition to occur (Ngyen & Aiello, op cit), there is currently an urgent need for innovative and transdisciplinary approaches to stimulate knowledge exchange and feedback throughout the chain of stakeholders involved in city development. One could refer to this as a need for structural societal change that result from economic, cultural, technological, institutional as well as environmental developments, which effectively influence and strengthen each other (Rotmans 2005). New business models, scalable public services and commercial applications may develop from innovative quadruple helix approaches, in which for example a local city council, industry and academia join forces to engage citizens in the energy and climate debate. It is not uncommon that a temporary building structure becomes the focal point of such collaborative efforts. In this paper, we present preliminary evaluations from a sustainability initiative in Stockholm that has a temporary building as its centre of activities, the Dome of Visions. Our objective is to discuss how innovative transdisciplinary initiatives that centre around a temporary shared space – with the explicit intent to promote social sustainability and save energy – can be evaluated from an energy perspective.

1.2 Temporary buildings

Temporary buildings are increasingly used in our society, as extraordinary measures to solve a space deficit or in a situation when conventional spaces are not deemed suitable for the activity at hand. While conventional meeting-spaces within the existing building-stock are designed to provide adequate climate comfort and also conform to energy regulations, they often do not match the spatial needs that innovative and transdisciplinary activities require. If the existing building-stock is insufficiently well adapted to host innovative practices, it is of course valuable to learn from such new initiatives. At the same time, it is important to ensure that temporary structures are designed in ways that meet necessary energy requirements whilst also ensuring adequate climate comfort. A basic literature overview was conducted using the keywords *temporary buildings, portable buildings, barracks, portable homes, temporary homes* which showed that literature on the energy efficiency and indoor climate of temporary buildings is surprisingly scarce. The lacking knowledge about temporary buildings may lead to unfortunate compromises, both in the design, procurement and use of temporary meeting spaces. We reason that in the case of innovation-driven or transdisciplinary activities, social and economic success factors may sometimes overshadow the need to consider the environmental footprint. Or, lead to compromises regarding climate comfort. Further, it may be the case that (as in our use-case) a life cycle assessment of building materials, furniture and other activity-related goods is effectuated, while scrutiny of the building's energy consumption is neglected. From the above, several important questions can be formulated, motivated by the increased use of temporary spaces in society: (1) Are temporary building structures sufficiently effective, from an energy standpoint, to motivate use as publicly shared spaces in smart sustainable city contexts?; (2) Is climate comfort (and indoor air quality) sufficiently well procured; and comparable to 'business-as-usual' meeting spaces? For the Stockholm's case, the first question would require a full sustainability evaluation of the Dome of Visions in terms of ecological, social, and economic sustainability, which has not been possible within the limited framework of this paper. We have therefore focused on the second question by performing an evaluation of the climate comfort and indoor air quality of two meeting rooms in the Dome of Visions, in the aim to further explore the priorities and mechanisms involved when transdisciplinary initiatives are launched to promote energy awareness in publicly shared spaces. In the following sections, we introduce the use case and present our results, which we subsequently discuss as a basis for a few conclusive remarks in the final section.

1.3 The Dome of Visions

Our use-case is the Dome of Visions[2], a temporary building on KTH campus 2015-2017, which has successfully established an innovative publicly shared space for events, meetings and exhibitions in a relatively short period of time (Fig. 1-2). The initiative is jointly hosted by KTH and the Swedish construction company NCC to address relevant themes within sustainable development.[3] To date, 50000 visitors have participated in more than 400 curated events, such as exhibitions, seminars, lectures and artistic performances.

Fig. 1: The Dome of Visions is located on KTH campus in the city centre of Stockholm. The cupola was designed by the Danish architect Kristoffer Tejlgaard and constructed entirely from an ecological cradle-to-cradle approach. The Dome is open daily 10AM-16PM and offers a public venue that both citizens, academia and industry can share for events, seminars, cultural installations or to exhibit prototypes and other results from teaching and research. Commercial partners pay to use the Dome as a shared space for events, while academic and cultural institutions do not.

With the ambition of a passively heated building with minimum energy use, the Dome of Visions was procured and constructed by NCC with a cradle-to-cradle approach. All building materials are biodegradable or possible to recycle. The cupola is made from massive wood shielded with polycarbonate, which gives the interior the characteristic of a greenhouse, with an indoor temperature and air quality that follows the cycle of the Stockholm climate throughout the year. In winter, the temperature in the greenhouse will often drop closer to 0°C, while it can reach well above 30°C in

[2] For more information and an overview of scheduled events September 2015-October 2017, see www.domeofvisions.se and https://www.facebook.com/domeofvisionsSE.

[3] A Head Curator, recruited from the arts, is responsible for a programme that addresses a sequence of themes, formulated by the project steering group, consisting of representatives from NCC and KTH. Project partners include the City of Stockholm, IVL Swedish Environmental Institute, Akademiska Hus, Open Lab and Stockholm University of the Arts.

late spring when the sun is out. Excess heat is evacuated from the roof top and to prevent the surface from steaming up when the temperature changes, an under-floor heat-pump ventilates humidity away by distributing hot air alongside the façade. Fire regulations enable seated events with up to 150 visitors but in more extreme weather conditions, the greenhouse is typically used for stand-up gatherings, bar-mingle and exhibitions. However, an interior pavilion offers two meeting-rooms which are heated to room temperature during the winter months, using district heating (Fig 2.). The interior pavilion is only partly insulated and not designed to store heat, the greenhouse therefore benefits from a small amount of excess heat.

A web interface enables visitors to follow the indoor climate changes in real-time, or to check if a space is free, based on sensor data that is collected by experimental weather stations installed in different locations.[4] (Fig. 3) The original objective was to enable students and researchers to programme innovative applications and IoT-services based on real-time sensor-feedback and actuators (e.g. iBeacons) that recognise visitors to the Dome, as part of ongoing research on immersive spaces and mediating presence (Gullström 2016; Gullström & Kort 2016). This sensor data has provided a sufficient basis for evaluations presented in the next section. Programmed activities in the dome are also shared online, primarily via Facebook, and publicly accessible to all, which is why we define the venue as an innovative shared space within the sharing economy.

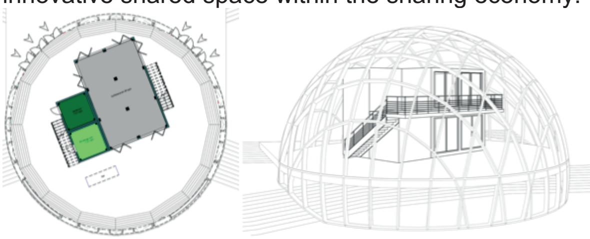

Fig. 2: The Dome has a diameter of 16 metres (200 sqm built area) and in addition to the various open spaces offered inside the greenhouse, a wooden pavilion provides two meeting rooms. The floorplan on the left shows the larger meeting room on the ground floor ("Dome #3), above which the smaller room is located (Dome #2), seen on the perspective. The pavilion in the Dome was designed by the KTH architecture student Stefania Dinea, following a student competition in 2014.[5]

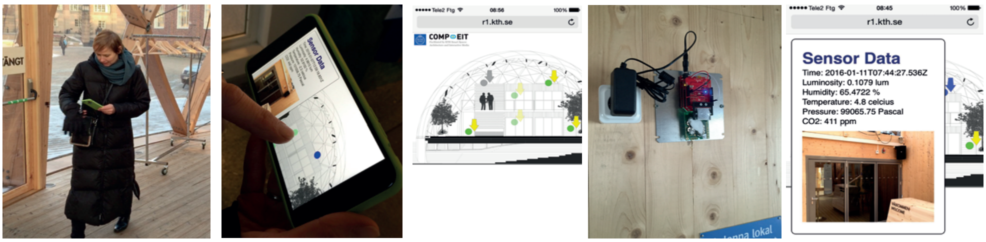

Fig. 3: A basic web interface gives visitors easy access to real-time sensor data. Experimental weather stations have been placed in different locations inside the Dome of Visions.

[4] Visitors can access live data here: r1.kth.se/DomeOfVisions. Stored data is available here: http://smartspaces.r1.kth.se:8082. The research group *KTH Smart Spaces: Architecture and Interactive Media* installed five Arduino-based sensor kits that measure relative humidity (h=%); pressure (p=Pa); ambient light (l=Lumen); carbon dioxide (c=ppm), and finally movement (measures 150 samples /min in 10 minute frames. Key: pp = no of positive data from last measurements, i.e.movement registered; np = no of identical data from last movement, i.e. no movement registered).

[5] The Dome of Visions project was originally initiated by the corresponding author, with the interest to let architecture students design a pavilion 'for extreme environments' that could be built on campus. The student competition was organised as part of this, together with NCC. The ambitions of the project grew when industry partner NCC offered to construct a cupola around such a pavilion, following successful trails with the Dome of Visions in Denmark, hereby enabling KTH and NCC to launch a joint energy initiative.

2. Evaluation of climate comfort and air quality

2.1 Data collection

Based on the sensor data that the dome has generated in the past year, we have performed an evaluation of climate comfort and air quality of the two rooms in the Dome of Visions that are designed to host seminars and meetings throughout the year, which means that they are heated to room temperature also during the winter months.

The larger meeting room on the ground floor (50sqm, labelled "Dome #3") is customized for 40-50 participants but can fit up to 70 people; while the smaller room on the first floor (30sqm, "Dome #2") is customized for 15-20 people but can fit up to 30 participants. We have plotted the main thermal comfort and indoor air quality for the rooms over one year and selected two days that can be deemed representative of the warm and cold season. We have qualitatively inferred occupancy times from the comparison of indoor CO2 concentration and temperature. To make generalized conclusions further statistical analysis would be needed, for instance by correlating outdoor temperature with the indoor temperature, RH and CO2 to systematically infer occupancy, still in a simplified way.

2.2 Overall plot of thermal comfort and indoor dry-air temperature

The overall plot of the ground floor meeting room, Dome #3 (Figure 4, left) shows that from the point of view of the thermal comfort, indoor dry-air temperature is above 26°C for 11% and below 20°C for 32% of the monitored time warm season. Low temperatures (as low as 13°C) occur in the winter season (January). The relative humidity is below 30% for 50% of the same time, mainly during the cold season, which results in too dry air. Further, we note that the: Indoor air quality appears to be generally poor, with CO_2 concentration above 1000 ppm on several occasions (accounting for 1% of the overall monitored time, including no-occupancy time) and with peaks above 2000 ppm; such conditions may be indicative of an under-dimensioned ventilation system.

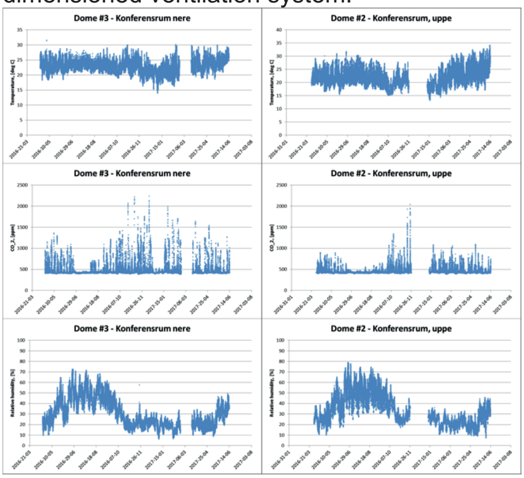

Fig. 4: Long term plot of indoor dry air temperature, relative humidity and CO_2 concentration for the room located in the ground floor of the Dome of Visions (left), and on the first floor (right).

The overall plot of the first floor meeting room, Dome #2 (Figure 4, right) shows that from the point of view of the thermal comfort, the indoor dry-air temperature oscillates considerably throughout the year, with uncomfortably high temperatures during the warm season and low temperatures (as low as 13 °C) in winter season (January); relative humidity is generally low in the cold season and high during the warm season, causing not ideal indoor conditions. We also remark that:

- If the building has been designed to be kept under comfort conditions even when no occupants are in the Dome, this indicates the inability of the heating and cooling system to comply with design requirements;
- From the point of view of Indoor Air Quality, the CO_2 concentration is below 1000 ppm for most of the time, indicating not optimal but acceptable indoor air quality; however, CO_2 concentration higher than 2000 ppm also occurs, indicating occupancy well above design conditions; such conditions are likely to be perceived as highly unsatisfactory by the occupants, with potential dizziness occurring;
- The above mentioned indoor conditions should be interpreted in the light of a more limited occupation of the building and may be less critical than a long term occupied building.

2.3 Example of a week in the cold season: 21-26/11/2016

Figure 5, left, shows that in the cold season, the temperature in the meeting-room on the ground floor (Dome #3) is too high when people are in the room. A temperature peak of 28 °C is reached on 12/12/2017, with CO_2 concentration above 2000 ppm. Further, the indoor temperature is kept at 23-24 °C when the room is mostly unoccupied; significant energy savings may be obtained by:

- increasing the set-point temperature when people are in (e.g., 20 °C);
- further lowering the temperature during unoccupied time slots.

Figure 5, centre, shows the equivalent for the meeting room on the first floor (Dome #2)
shows a peak of temperature and CO_2 concentration on 23/11/2016. This is most likely due to insufficient ventilation and can easily be resolved:

- Indoor set-point temperature could be decreased to decrease energy use for heating;
- from the comparison of the indoor temperature and the CO_2 concentration, it can be noted that the room is heated when left unused, a potential energy saving is thus identified.

The temperature peak on 12/12/2016 in the larger meeting room has been validated by the Dome of Visions programme records, confirming that two large events took place on this day (Fig 5, right). We also selected a week in the warm season (22-27/5/2017) and noted peaks of indoor temperature at 30°C, which can be considered uncomfortable if the room is used. In the meeting-room on the first floor (Dome #2) we also documented a sudden increase of the temperature, probably due to solar radiation, either as solar gains through the windows or hitting the sensor.

3. Discussion

In terms of social and economic sustainability it is clearly documented that the Dome of Visions has created an innovative, attractive and informal meeting space which has enabled new encounters between academia, industry, public authorities and citizens of Stockholm; a shared space open for all and free of charge, and as such it can be assessed as part of the sharing economy. The Dome of Visions succeeded in activating campus in a way that secures integration, on an urban level, to the city which has motivated the City of Stockholm and Akademiska Hus (the real estate company in charge of Swedish university campuses) to welcome similar initiatives in the future. It is worth noting that it only became possible to introduce a design such as the Dome of Visions in a delicate cultural heritage site (such as KTH campus represents in the centre of Stockholm) following a recent change in planning regulations, which has made possible building permits for temporary architectural structures in Sweden.

Fig. 5: Plots of indoor dry air temperature, CO_2 concentration and relative humidity for the week 12-17/12/2016, to the left the room on the ground floor Dome #3. Centre, the room on the first floor, Dome #2. To the right we see how, on12/12/2016 the larger meeting room was filled with 56 seated guests and 14 standing guests between 2-6PM[6]. This even was preceded by a lunch talk by the "Centre for Land Use" with 20 participants 12-13PM.[7]

From the point of view of comfort and indoor air quality, the results are less encouraging. We clearly documented situations of discomfort in both meeting rooms. These are primarily caused by insufficient ventilation (in some days the CO2 concentration reached 2000 ppm), and too warm temperatures, also in the cold season, a problem that however can be tackled by improved control strategies. From an energy standpoint, the evaluation shows that the indoor set-point temperatures are too high, especially in considering that the rooms are heated also when they are unused (verified from negative increase of CO2 concentration).

The above findings support our view that while the Dome of Visions, as a project initiative has generated a range of valuable programme activities and triggered fruitful citizen debate; its founders and designers have been less concerned with the energy efficiency and energy consumption of the building in itself. This is perhaps symptomatic of the emergency and short-term thinking that characterizes temporary buildings – whether it is schools in need of surplus classrooms, or councils in need of immediate housing for refugees – environmental impact and energy efficiency are not primarily called for.

The Stockholm use case shows that social and economic factors are prioritized. Further research and development work to improve the design and energy efficiency of temporary buildings is called for, given the increasing usage of temporary structures in our society.

[6] Information about the event "Changing What We Eat" can be found here http://artandscienceinitiative.org/CWE and http://domeofvisions.se/evenemang/changing-what-we-eat/
[7] http://domeofvisions.se/evenemang/1006/

4. Concluding remarks

We end with a few concluding remarks given that temporary buildings play an increasingly important role in today's society. They suddenly populate and activate public space in our cities in order to meet a variety of challenges that citizens may not be aware that a city should take responsibility for. On the one hand, a temporary building can provide instant shelter for refugees, easily transported, dismantled and reassembled anywhere in the world. On the other hand, temporary and unconventional venues are also needed for innovative and transdisciplinary initiatives, conferences and other practices with spatial requirements that seemingly cannot be met within the existing building-stock or institutional 'silos'. It is important to further investigate why existing institutions do not seem to be able to accommodate innovative add-on practices. It appears that completely new spatial entities are needed to host events that leak from one institution to another, or that require collaboration between institutions. We also know that temporary structures often appropriate school playgrounds for longer than what should be possible to consider temporary – meaning that the temporary can easily shift into permanence, for example if a school cannot provide sufficient learning spaces – all the more reason to ensure that temporary buildings are designed to be energy-efficient.

The basis for this paper was our interest in emerging cross-sectorial and interdisciplinary approaches –even citizen-driven and bottom-up initiatives – that we notice may fruitfully develop into testbeds and living-labs with high relevance for research relating to the future planning of smart sustainable cities. We believe that quadruple-helix approaches in energy research can learn from such initiatives that seek to break silos by innovative and temporary place-making activities in the city. While it may be argued that temporary buildings should conform to the same regulations as generally prevails, we would like to conclude that also from an energy innovation perspective, temporary buildings provide fruitful testbeds to test new solutions.

5. Acknowledgements

Architect Stefania Dinea and NCC have contributed work drawings and details about the Dome of Visions structure.

The Curating Team of the Dome of Visions, Björn Norberg and Charlotte Saltskog, have contributed valuable information on the programme activities.

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6. Literature

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ICT in the built environment: Drivers, barriers and uncertainties

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Abstract

Buildings are major contributors to energy use and environmental impact in developed societies. If the ambitious sustainability targets of modern societies are to be met, energy use in the built environment must be addressed as a central issue.

New momentum on achieving energy efficiency in the building sector has been triggered by information and communication technology (ICT). New opportunities bringing the concept of smart building closer to reality are offered e.g. by innovative sensing techniques, extensive and cost-efficient data collection and analysis, advanced controls and artificial intelligence.

However, these opportunities are associated with cost and uncertainties regarding whether the investment costs are paid back in terms of energy savings, whether indoor comfort and air quality and improved, the drawbacks in term of increased maintenance effort, complexity, reliability and resilience, the effects in terms of user interaction, how data security is affected and the long-term effects on society.

This paper critically analyses recent research findings and reviews the pros and cons of some promising ICT techniques being applied in the building sector. It exemplifies drivers and barriers to implementation of advanced controls and artificial intelligence in buildings, based on findings from two test-beds in Stockholm, and discusses the implications of these findings for future research.

Keywords: energy efficiency, information and communication technology, sustainability, built environment

1. Introduction

Buildings are estimated to account for 30% of overall energy use and 40% of CO_2 emissions in developed countries (Berardi 2013). Information and communication technology (ICT) has been shown to enable and determine energy efficiency in the built environment, e.g. through advanced controls, energy monitoring and fault detection and promotion of energy-efficient behaviours (Faruqui, Sergici and Sharif 2010; Hargreaves, Nye and Burgess 2010, 2013). It is unsurprising that smart homes are a high priority in the EU Strategic Energy Technology Action Plan (Wilson, Hargreaves and Hauxwell-Baldwin 2017).

Smart homes have been defined as home-like environments that possess ambient intelligence and automatic control, which allows them to respond to the behaviour of residents and provide them with various facilities (De Silva, Morikawa and Petra 2012). Smart homes offer potential features that go beyond the capabilities in current buildings, such as improved security, assisted living and e-health capability, augmented entertainment, communication and visualisation (e.g. with feedback on energy use), improved comfort and indoor air quality and more efficient use of energy (Balta-Ozkan et al. 2013).

Smart buildings are expected to play a relevant role as units in smart sustainable cities, and have been the object of great attention in the literature in recent years (see e.g. the review by Solaimani, Keijzer-Broers and Bouwman 2015). The present paper summarises the most recent findings in the literature concerning opportunities and challenges encountered in implementation of smart homes and illustrates the findings with examples of current research on smart buildings at the Royal Institute of Technology (KTH) in Stockholm. The following sections present a brief summary of drivers, barriers and uncertainties reported in the literature and describe experiences from two examples of smart buildings, the KTH EES Q Building Testbed and the KTH Live-In Lab, which are compared against literature findings.

2. Drivers

Smart homes can provide assisted living and home tele-health capabilities. The possibility of maintaining good health and independence for the elderly is undoubtedly among the main drivers for implementation of smart homes in societies with an ageing population. Smart homes can offer the possibility to provide assurance, enhance impaired physical functions and assess the cognitive status of the elderly, contributing to improved quality of life (Chan et al. 2009). Although home tele-health and telemedicine still seem to remain in the research domain and determination of their cost-effectiveness may require further studies (Chan et al. 2009), the evolution of technologies involved in smart homes will most likely change the way houses appear and are used (De Silva, Morikawa and Petra 2012). However, Chan et al. (2008) warn that in the past 20 years, smart homes have failed to achieve the anticipated results.

Another crucial driver for the implementation of smart homes is the potential to play a primary role in environmental sustainability through improved energy efficiency. Building automation and advanced controls have been proven to have the capability to reduce the energy demand in buildings. For instance, tests of model predictive control schemes in a university building in Prague revealed an overall heating demand reduction of between 15 and 28 % compared with the baseline controller (Prívara et al. 2011; Široký et al. 2011). Similarly, the relevant Swedish standard (SS-EN_15232: 2012) estimates that the potential energy savings deriving from building automation control systems (BACs) lie within the range 14-50% for thermal energy in non-residential buildings, and are 19% in residential buildings, when baseline and highly energy efficient BACs are compared. Highly energy efficient BACs are capable of setting appropriate indoor temperatures when people are present, maintaining indoor comfort and avoiding unnecessary energy use when indoor spaces are not used. Obviously, the energy savings from building automation and ICT vary depending on building location, geometry, materials and heating, ventilation and air conditioning (HVAC) design, but these figures are indicative of the relevant energy saving potential.

In a survey on the impact of user behaviour on energy use in buildings, Nguyen and Aiello (2013) found the experimental energy saving in lights and plug loads to be 13-25% and 14%, respectively, with higher potential when simulations were involved.

Through energy monitoring, feedback to users and automated control, smart homes have the potential to promote energy-efficient behaviours, which can reduce energy demand by 30% (Nguyen and Aiello 2013), and prevent the so-called energy rebound effect (Hens, Parijs and Deurinck 2010). Otherwise the potential energy rebound effect is estimated to be up to 30% (Haas, Auer and Biermayr 1998; Haas and Biermayr 2000).

It important to stress that the EU Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020, while by 2018 all new public buildings must be nearly zero-energy (EC 2013). Building automation and energy monitoring can be a key factor in ensuring that buildings operate as designed, both when commissioned and during their life span.

3. Barriers and uncertainties

The main barriers to adoption of smart buildings are often categorised as technical, administrative and societal. Among the technical barriers are complexity, interoperability and reliability (Balta-Ozkan et al. 2013). A social challenge is the 'fit', which is the capability of smart homes technologies and service to be integrated into the design, lifestyle and general sense of home (Balta-Ozkan et al. 2013).

Privacy is often seen as another major barrier by both experts and users, with concerns about physical security and the risk of smart systems being hacked and data falling into the wrong hands (Balta-Ozkan et al. 2013b). Similarly, Friedewald et al. (2007) identified surveillance of users, identity theft and malicious attacks as the main risks related to privacy in smart homes.

Bulut et al. (2016) focused on the financial uncertainties in implementation of active buildings in the smart grid in Sweden, identifying high investment costs, low electricity price, lack of suitable business models to cope with investment and revenues uncertainty and the problem of ownership (i.e. who should make the investment) as main barriers among active building stakeholders.

4. Experiences from two testbeds: KTH EES Q Building Testbed and KTH Live-In Lab

A number of activities in the area of smart buildings have been initiated at KTH, with two buildings, a testbed and a living lab, being the flagship areas for testing and research. The following subsections briefly describe the building facilities and the experience gained so far.

4.1. KTH EES Q building testbed

The EES Q Building Testbed is housed on the KTH main campus, in the ground floor of a seven-story office building with a heavyweight concrete structure (Figure 1). The testbed consists of four rooms: a laboratory and three student offices. The rooms are all equipped with supervisory control and data acquisition (SCADA) and programmable logic controllers (PLCs), a wireless sensor network, an actuator network and a weather station.

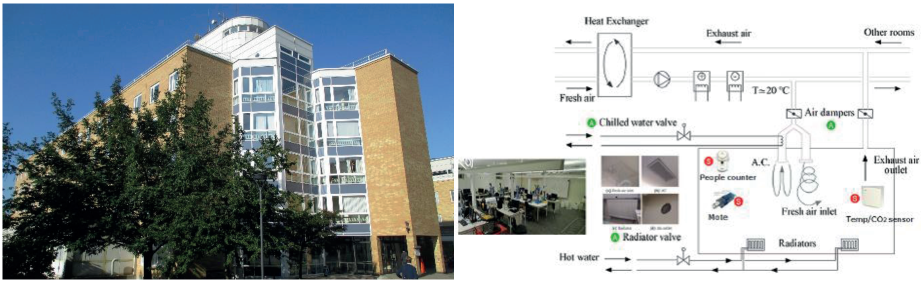

Figure 1: Building enclosure, heating and ventilation scheme of the EES Q Building Testbed at KTH.

The installed sensors enable continuous monitoring of the status of the system, e.g. room air CO_2 concentration, temperature, humidity, and external weather conditions. The implemented platform also gathers data from weather forecasting services and is integrated with web-based scheduling services (calendars) of the occupancy of the rooms. Occupancy is measured through a photoelectric-based people counter. The HVAC system of the rooms consists of a ventilation system supplying fresh air plus a radiator heating system. Air is vented from a central air handling unit with heat recovery into the rooms by a fan running by default between 8:00 and 15:00 h during weekdays. When the central fan is on, a minimum air flow is distributed into the rooms, irrespective of their occupancy, due to building regulations. The heating system uses standard waterborne radiators as heat emission units.

The EES Q Building Testbed is an experimental laboratory and the considerations here are only partially applicable to smart homes, but some conclusions and similarities with the previous literature can be identified. The main purpose of the testbed is to test innovative schemes for control to improve indoor comfort and minimise energy use in buildings. Specifically, a deterministic model predictive control and a stochastic model predictive control have been tested and compared with the standard control approach (PI controller). The results show that the proposed control approaches are capable of reliably improving indoor comfort and reducing energy use (Parisio et al. 2013, 2014). Remarkably, the full energy saving potential could not be reached due to building regulations that mandate a certain amount of ventilation in all rooms regardless of occupancy.

However, the encouraging results achieved in the testbed needed extensive labour inputs to properly equip the building with additional sensors, as existing sensors were designed for basic control and not suitable for accurately monitoring energy flows. It is important to stress that even if buildings are often equipped with various sensors, these are usually designed for billing or control purposes and their resolution may prove inadequate for proper monitoring, and in particular for determining how efficiently energy is used in indoor spaces with respect to occupancy and comfort. The testing of advanced controls also required a different set of software tools that needed to be combined in a tailored configuration to interoperate reliably, adding to the complexity of the project. In addition, the experimental set-up required specialist expertise to be properly maintained. A partial solution to these issues, for instance for energy monitoring, might be provided by commercial solutions in low cost computers like Arduino and Raspberry Pi and the set of libraries developed and available on the internet. In the EES Q Building Testbed, the issue of maintenance for critical applications was solved by means of redundancies, for instance by providing a simple and more reliable controller for the HVAC, to be used if the experimental controller failed, although failure did not occur.

From the point of view of energy efficiency, issues arose in the interaction between users and the system, which highlights the importance of flexible and adaptive control schemes in the building. Set points and schedules were designed for energy efficiency, for instance reducing the time during which ventilation operated to the slots in which the rooms were scheduled to be occupied. However, the rooms were often occupied beyond the expected time frame, leading to poor indoor air quality. As a reaction people tended to open the windows, causing thermal discomfort comfort due to low winter temperatures, and the windows were then often left open (no opening sensor was present), thus increasing the energy consumption when the ventilation was operative again on the following day due to bypassing of the air recovery system.

4.2. KTH Live-In Lab

The KTH Live-In Lab (Figure 2) is a platform for research, testing and education to promote innovation in the building sector and consists of both virtual and physical test environments. The Live-In Lab is housed in three residential buildings, currently under construction, for approximately 300 studio apartments located in the main campus at KTH in Stockholm, next to the EES Q Building Testbed. Heating and cooling power to the buildings is provided by ground-source heat pumps. Heat is distributed airborne to the apartments through thermally activated building slabs that provide ventilation and heat distribution at the same time. Electricity is generated locally with photovoltaic (PV) panels installed on the flat roof, and the installation of storage systems, in particular batteries for electricity, is under discussion.

The buildings comprise passive and active parts. The passive part accounts for the majority of the floor area and is designed to be extensively equipped with state-of-the art sensor devices to log indoor and outdoor environmental parameters (e.g. temperature, humidity, light etc.), primarily for continuous, real-time monitoring of indoor comfort and energy use. In the initial phase of the project, the passive part will be used only for monitoring. The active part accounts for approximately 300 m^2 of floor area and will be used for more active testing in which the experimental set-up, including the layout of the apartments in this area, will be periodically changed, allowing a holistic approach to the research on buildings. The active part has a dedicated heating and cooling system and energy is provided with a separate heat pump and boreholes. Advanced monitoring and control will be tested and fine-tuned there, and then applied to the rest of the building.

Figure 2: Computer-generated image of the Live-In Lab [source: property developer Einar Mattsson].

Although the KTH Live-In Lab is still in the construction phase, some preliminary considerations can be reported. In the design phase of a smart building, it may be difficult for all stakeholders to fully understand the potential advantages of new technologies, and simpler technologies, for instance for energy monitoring and HVAC control, may be preferred. Furthermore, there is a risk that adoption of new technologies may prove more expensive, due to the lack of necessary procedures and expertise for design, installation and maintenance.

5. Discussion and conclusions

This paper briefly reviewed some of the main drivers and challenges to implementation of smart homes identified in the literature and in ongoing research at KTH. Smart buildings offer invaluable potential, but are complex and evolving systems. To unlock their potential, it is crucial that all stakeholders (constructors, designers, users) understand their advantages and limitations. To this end, demonstration projects, testbed and semi-experimental buildings, like the KTH EES Q Building Testbed and the KTH Live-In Lab, are crucial in transferring experiences developed in testbeds to all relevant stakeholders.

Technical challenges may be addressed and fixed, but business models and the need to properly define value creation must be addressed if smart homes are to make the expected impact in the built environment. Even if energy savings per se may not always make the extra investment involved in smart buildings economically viable nowadays, sharing the same ICT infrastructure across multiple services (improved indoor control, security, telecare etc.) is likely to change this picture.

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Tracing urban carbon flow in the global economy system: Consumption vs production perspectives

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Abstract

A global environmentally extended multi scale input-output model (EE-MSIO) was developed to track accurately the carbon flow in the global economic system from production and consumption perspectives. Beijing was selected as the case, and results were as follow. In 2010, the consumption-based carbon (210.31 $MtCO_2e$) is 2.13 times of production-based carbon (98.93 $MtCO_2e$); and 76% of consumption-based carbon emissions occurred outside Beijing's geographic boundary. Neighboring Hebei province is the largest origin of imported carbon, and Jiangsu is the largest destination of exported carbon form Beijing; Russia and U.S. are the main embodied carbon importing countries, and U.S. and Japan are the main embodied carbon exporting countries. These findings suggest that more regional coordination and trade adjustment should be strengthened to truckle global climate change due to the significant effects of interprovincial and international trade on local carbon emissions. And urban consumption patterns should also be concentrated on to guide the the setting of urban carbon mitigation targets.

1. Introduction

Accounting the urban carbon profiles induced by energy consumption has been widely conducted in recent years (Liu et al. 2012, 2013; Meng et al. 2017). Carbon flow is one of the flows of these profiles that are closely connected to the urban metabolic system (Yan et al. 2014). And it is a valuable indicator in understanding the both the direct and indirect, on-site and off-site greenhouse gas (GHG) emissions (Wright and Kemp 2011, Lin et al. 2015).

Regarding CO_2 emissions at the city level, an open urban economy induces CO_2 emissions beyond its geographic boundaries via both international and domestic trade (Lin et al. 2017). Considering the full impact of urban activities on global carbon emissions, the accurate carbon flow analysis at the city-scale faces many challenges. Therefore, the responsibility for urban CO_2 emissions reduction should not be confined to local government but should instead include collaboration among local, national and global policymakers by considering industry specialization and trade policy differences (Feng et al. 2013, Feng et al. 2014). The issues need to be addressed include how to trace accurately the urban carbon flow avoided by domestic and foreign trades and how to allocate responsibilities for an urban economy's carbon emissions.

Researches have concentrated on the urban carbon flow mainly by the production-based accounting (PBA) and consumption-based accounting (CBA) perspectives. Production-based carbon flows are caused by domestic production, including export (Peters 2008). It accounts for CO_2 emission at the point of production, without consideration of where goods are used or who ultimately uses them. It neglects indirect carbon emissions embodied in the supply chain, resulting in carbon leakage which undermines the effects of international climate policies (Atkinson et al. 2011). PBA approach is widely used in global climate change agreements, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Mi et al. 2016). CBA approach allcoates emissions occurring along the chains of the production and distribution to the final consumers rather than the producers (Brizga et al. 2017). Consumption-based carbon flows include imports emissions embodied in trade but exclude exports. It has been increasingly used in a policy context to provide an understanding of the emissions embodied in trade (Mi et al. 2016).

Input-output analysis (IOA) is the main approach for trace urban carbon flow in the global economic system. However, conventional IOA at city scale was originally based on the assumption that technical level associated with both the domestic and foreign imports was equal to that of local outputs. The homogeneity assumption induces the inaccurate results for a modern city, supported by massive domestic and foreign imports, with large difference between the intensities of economies at various scales. In order to address the technical issue, researchers have improved the conventional IOA to distinguish the embodied intensities in the local, domestic and worldwide economies (Lin, Hu et al. 2015, Hu, Lin et al. 2016, Lin, Hu et al. 2017). However, these researches did not conduct accurate spatial distribution analysis of urban carbon flow in the domestic and worldwide range. In this paper, we constructed an environmentally extended multi-scale input-output model (EE-MSIO) (including city-nation-globe) to track accurately the carbon flow in the global economic system based on the PBA and CBA perspectives.

The paper is organized as follows: (1) introducing the calculating methodology; (2) applying the EE-MSIO model to track carbon flow for Beijing City; (3) drawing conclusions and policy implications based on results.

2. Materials and Methods

In this study, we constructed the EE-MSIO model including city-nation-globe the three scales. Its core is a multi-regional input-output table (MRIOT) describing product exchanges within and among city-nation-globe economic system, by linking the MRIOT of Chinese provinces in 2010 (Liu et al. 2010) with the WIOT in 2010, which is based on the World Input Output Database (WIOD)[1]. The main linking method was described in more detail by Peters et al. (Peters et al. 2011). It assumed that the international exports of each sector in a province are distributed among importing sectors in foreign countries in the same ratio as China's total exports. And the detailed equation is as follows:

$$T_{ij}^{ps} = \frac{T_{ij}^{Cs}}{\sum_{s}\sum_{j} T_{ij}^{Cs}} \sum_{s}\sum_{j} T_{ij}^{ps}$$

Where, T_{ij}^{ps} is the export monetary flow from sector *i* in regions *p* in MRIOT of Chinese provinces to sector *j* in region *s* in WIODT; T_{ij}^{Cs} is the total export monetary flow from China to region s in WIODT.

And the same formula can also be used to evaluate T_{ij}^{sp}. For easier understanding the results and discussions, the 70 regions are organized in 8 Mainland China regions and 10 world regions: Beijing, North (Tianjin, Hebei, Shandong), Northeast (Heilongjiang, Jilin, Liaoning), Central (Henan, Shanxi, Anhui, Jiangxi, Hubei, Hunan), Central coast (Henan, Shanxi, Anhui, Jiangxi, Hubei, Hunan), South coast (Fujian, Guangdong, Hainan); Northwest (Inner Mongolia, Shannxi, Gansu, Qinghai, Ningxia, Xinjiang), Southwest (Guangxi, Chongqing, Sichuan, Guizhou, Yunnan); Russia, Austria, Brazil, India, Indonesia, North America (USA, Mexico, Canada), East Asia (Japan, Korea), European Countries (Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Slovenia, Spain, Bulgaria, Czech Rep, Denmark, Hungary, Latvia, Lithuania, Poland, Romania, Sweden, the UK, Turkey), Other Countries.

In this study, the carbon emission inventories considered energy use, non-energy use (only including agriculture production), in the form of carbon dioxide equivalent (CO_2e), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The carbon emissions of 30 provinces in China (including Beijing) were calculated based on IPCC approach, detailed method description

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[1] http://www.wiod.org.

referring to (Meng et al.; Lin et al. 2013). The activity data were mainly from the China's Provincial Energy Statistics and some additional agricultural data were from the China Agriculture Yearbook. The emission factors were taken from IPCC guidelines and the National Greenhouse Gas Inventory, referring to (Meng et al.). And the carbon emissions of WIOD regions were taken from the environmental satellite account in WIOD.

3. Results analysis

In this paper, EE-MSIO model was constructed to track the carbon flow of Beijing City in 2010 based on PBA and CBA approaches. And the results are seen as Fig.1 (a)-(c), where: (1) from Fig.1(b), production-based carbon emission that occurred within urban territorial boundaries was 98.93 Mt CO_2e, of which, 51% was induced in the local production process of products and services for local consumption; 20% was caused by the production process of foreign exported products and services; 29% was for the domestic exported products and services. Consumption-based carbon emission was 210.31 Mt CO_2e, of which, 24% was induced by local production; 76% of carbon emissions related to goods consumed in Beijing occurred outside the city boundary, indicated by (Feng et al. 2014). It confirms that city as a consumer role is largely depending on products and services produced elsewhere, thus imposing emissions to other regions home and abroad. (2) from Fig.1(c), carbon emissions induced by domestic exported and imported goods and services are tracked and quantified. From the structure, we can see that the three largest regions for domestic carbon outflow is central coast (23%), north (19%) and central (15%), that is to say, the carbon emissions transferred from these regions were undertaken by Beijing, accounting for 57% of the carbon emission occurred within Beijing's geographic boundary based on PBA approach. The three largest regions for domestic carbon inflow account for as much as 70% of the carbon emissions from domestic imports, respectively for north (25%), northwest (24%) and central (21%). Energy and heavy chemical industries are widely distributed in these regions and exported to provide powerful backup for Beijing's economic development. (3) from Fig.1(a), the carbon emission structure of foreign import and export in Beijing City is compared and analyzed. Up to 63% of the carbon emissions associated with goods consumed in Beijing were imported from foreign regions in 2010. Of which, Beijing outsourced 40%, 12% and 11% to Other Countries, East Asia and North America. As much as 74% of exported embodied carbon emissions flowed into North America (28%), European Countries (24%) and Other Countries (22%).

In addition, we accurately tracked the carbon flow across the 29 provinces (excluding Tibet and Taiwan) in China and 39 regions (including Taiwan, China and excluding Other Countries) in the world. As high as 52.24% of domestic imported embodied carbon emissions are focusing on Hebei, Inner Mongolia, Shanxi, Shandong and Jiangsu provinces. There are two main reasons: one is that it depends on the strongest geographical advantage, these provinces are all close to Beijing City; the other is that it depends on the economic structure of these provinces. Beijing as a consumer transfers the embodied carbon emissions caused by the final demand to those provinces exporting raw materials and products to Beijing. And 38.41% of domestic exported carbon emissions concentrate on Jiangsu, Tianjin, Shanghai, Hebei and Henan provinces. Expect for the neighboring Hebei and Henan province, the other three provinces are economically developed regions, importing high value-added products and services from Beijing to meet their final demand along with transferring the embodied carbon emissions to Beijing.

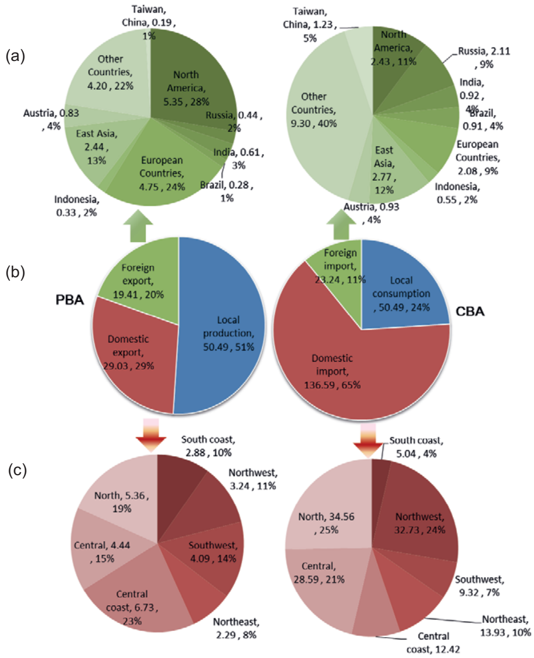

Fig.1. Structure of carbon emission based on PBA and CBA of Beijing City in 2010.

4. Conclusions and discussions

In this study, a global environmentally extended multi scale input-output (EE-MSIO) model was constructed and applied to track Beijing's carbon flow in the global economic system for 2010.

Carbon emissions that occur within territorial boundaries are calculated by PBA approach; those values are necessary but insufficient for assessing the contribution of human activities to carbon emissions and for guiding the measures of carbon emission mitigation. Compared with PBA, CBA indicate that substantial direct and indirect carbon emissions, from local production, domestic and international imports, representing the emissions induced by the final purchases of finished products. It can avoid the carbon emission leakage associated with trade, thereby linking economic activity with emissions and increasing mitigation options. In addition, it can also help urban government to widen and extend its policy options concerning local consumption patterns and regional collaboration on carbon emissions mitigation.

In terms of carbon flow of Beijing City, it found that the consumption-based carbon (210.31 MtCO_2e) is 2.13 times of production-based carbon (98.93 MtCO_2e); and 76% of consumption-based carbon emissions occurred outside Beijing's geographic boundary. From production perspective, 50% of the production-based carbon emissions were from local production activities for local consumption, 30% for domestic export, and 20% for international export. Trough the accurate carbon flows in the map, it showed that neighboring Hebei province is the largest origin of imported carbon, and Jiangsu is the largest destination of exported carbon form Beijing; while for embodied carbon flow of international trade, Russia and U.S. are the main embodied carbon importing countries, and U.S. and Japan are the main embodied carbon exporting countries. Current urban carbon reduction targets are set on the basis of the production-based carbon inventory. However, tradition PBA can only show the carbon quantity, unable to trace the detailed carbon flow to the trading regions at home and abroad. However, it can show the city's carbon contribution in the global supply chain. Meantime, the PBA maybe mislead the urban administrative managers to eliminate the energy intensive industries in order to fulfill the urban carbon reduction targets. However, the carbon emissions embodied in trade flowed following the exchange of products and services. The carbon reduction target of the larger country scale may not be achieved, even an increase in short term because of the demand of a new construction of manufacture facilities (Guan et al. 2014). Through the mapping of carbon flow in the global supply chain, it accelerates the realization of carbon reduction responsibilities of cities from consumption perspective. Strengthen the regional coordination and adjust the regional trade structure should be the main measures to tackle global climate change in the future. And urban consumption patterns should also be concentrated on to guide the the setting of urban carbon mitigation targets. It is more instructive and effective, especially for megacities as net consumers like Beijing.

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Energy efficiency and environmental sustainability indicators for papermaking from chemical pulp. A Finland case study.

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Abstract

Pulp and paper manufacturing, more than many other industries, plays an important role in sustainable development because its chief raw material –wood fiber– is renewable. This industry provides an example of how a resource can be managed to provide a sustained supply to meet society's current and future needs. However, this sector constitutes one of the largest industry segments in the world in term of water and energy usage as well as of the significant use and release of chemicals and combustion products. Only a minor role is played by forestry activities that supply the raw feedstock, although forestry management practices certainly affect both the final productivity and the energy balance, through the amount and use efficiency of the farm inputs. Hence, there is also an increasing need for assessing environmental costs and impacts of pulp and paper operations, considering both direct and indirect inputs supporting whole papermaking process as well as main outputs, co-products, and by-products.

By means of life cycle assessment method, this paper aims to assess the environmental sustainability associated to the pulp and paper production so as to identify those process steps that entail the highest environmental loads and require improvements. To determine the environmental impact as accurately as possible, the stages which caused environmental impacts were modelled on the basis of the manufacturing processes used by the pulp and paper mill complex of Stora Enso Oyj Veitsiluoto Mills at Kemi, Northern Finland. The obtained research results are a valuable source of management information for the decision makers at both company and national levels required to improve the environmental performance of paper production.

1. Introduction

One of the main means of reducing the threat of increased global warming, caused by human use of fossil fuels is to reduce the industrial use of energy (IPCC, 2014). For example, the results of modeling simulations by the IEA (2011) for the year 2035, suggest that under cost-minimization about half of the cumulative emission reductions required to meet the 2°C target would have to be achieved through improved energy-efficiency. In the industry sector, this share is even higher with about 60% (IEA, 2011). Among the energy-intensive industries worldwide, the pulp and paper industry is the fourth largest energy consumer (IEA, 2016). To maintain a high environmental performance, the pulp and paper industry has made important investments in more efficient production processes, where the reduction of energy and natural resources consumption have been a main topic. This is caused by increasing energy prices and the necessity to remain competitive in a challenged industry worldwide (Gaudreault et al., 2010). Moreover, the pulp and paper industry accounts for approximately 6% of total industrial energy consumption and 2% of direct carbon dioxide (CO_2) emissions from industrial sector worldwide (IEA, 2016). Although the pulp and paper industry ranks fourth in terms of energy consumption among industries, it is one of the least CO_2-intensive industries because of the widely production and utilization of renewable energy within this sector (around 50% of the primary energy consumption comes from biomass) (EC, 2015). This evolution has resulted in that, from 1991 to 2015, direct absolute CO_2 emissions have decreased by 18.2 %, whereas the pulp and paper production has increased by 50% and 22%, respectively (CEPI, 2016). However, given the projected continuing increase in pulp and paper production, future reductions (e.g., by 2030 or 2050) in energy use and CO_2 emissions will require additional efforts far beyond the best technologies available today. Innovations will likely include development of different processes and materials for pulp and paper production or technologies that can economically capture and store the CO_2 emissions. Thus, the definition of the environmental profile of this industry will be a key element in the pulp and paper industry's mid- and long-term climate change mitigation strategies. In this context, Life Cycle Assessment (LCA), a technique addressing the environmental aspects and potential environmental impacts of a product, process, or service throughout its life cycle (ISO 2006), has gained recognition as a tool that can provide environmental performance information to support decision-making in the design process.

Life cycle assessments and emission studies regarding the pulp and paper industry have been carried out in several countries, e.g. the US, Canada, Portugal, Germany, Norwegian, Sweden and China (Finnveden & Ekvall, 1998; Miner & Lucier, 2004; Salazar et al., 2006; Dias et al., 2007; Gaudreault et al., 2007, 2010; Ghose & Chinga-Carrasco, 2013). However, to the best of our knowledge, no LCA has been reported for the Finnish pulp and paper industry even though it is one of the most important producing and exporting countries of pulp and paper. Indeed, Finland is the second producer country in Europe (CEPI, 2016), with 10.1 million tons of paper and paperboard produced (Finnish Forest Industry Federation, 2017). Furthermore, among the energy intensive industries, the pulp and paper industry accounts for nearly 50% of the annual industrial energy use (Official Statistics of Finland), something which in turn implies that this sector in Finland will be an important target for the implementation of energy efficiency policies.

The most relevant stages in environmental impact are industrial activities related to high chemicals and energy consumption while a common finding is the minor role that forestry activities play on the whole process. This paper aims to assess and identify the environmental burdens associated to paper manufacture in Finland. To do so, a leading company producer of pulp and paper in Finland was analyzed in detail by using LCA. The objective of this work was thus: i) identifying the most efficient and cost effective options for increasing the environmental performance of the production of paper; ii) assessing the pulp and paper processes in order to identify opportunities for efficiency improvements, such as raw material use and energy saving.

2. Materials and methods

LCA is a methodology for the comprehensive assessment of the environmental impact associated to a product or process throughout its life cycle (from extraction of raw materials to product disposal at the end of use) and it is sometimes referred to as cradle-to-grave analysis (Guinée et al, 2001). However, when the system boundaries are restricted to selected life cycle stages, a cradle-to-gate perspective is possible, i.e. from raw materials extraction to product manufacture, which is the option followed in the present study. According to the ISO standards (ISO, 2006), LCA is compiled of several interrelated components: i) goal and scope definition; ii) inventory analysis; iii) impact assessment and iv) interpretation of results for explanation of conclusions and recommendations, which is the scheme followed in this paper.

2.1. Goal and scope definition

This work aims to analyze and quantify the environmental impacts associated to the production of paper, so as to identify those processes along the process chain that entail the highest environmental impacts. The study covers the whole cycle of paper production from raw materials production to the pulp and paper mills gate. Pulp and paper mill complex of Stora Enso Oyj Veitsiluoto Mill located in Kemi (Finland) was selected to carry out the study. The mills produce annually bleached pulp (420,000 tons), uncoated fine papers (580,000 tons), coated magazine papers (360,000 tons) and sawn goods (200,000 m^3)[1].

2.1.1. Functional unit

The functional unit (FU) provides a reference to which the inputs and outputs are normalized. In this study, 1 ton of paper produced in Finland was defined as the functional unit.

2.1.2. System definition and boundaries

Manufacturing of pulp and paper is not a single process but a series of unit processes, often linked and interdependent. In the papermaking process, wood logs are first debarked and chipped into small pieces or "woodchips". Then water and heat are added and by chemical processes the wood is separated into individual fibres (digesting). The spent liquor and its dissolved contaminants – referred to as "black liquor"– are washed away and sent to the chemical recovery process for energy production. After refining, the raw pulp is whitened by a bleaching process prior to the paper making phase. Then this pulp slurry is sprayed onto a flat wire screen which moves very quickly through the paper machine. Water drains out, and the fibres bond together. The web of paper is pressed between rolls which squeeze out more water and press it to make a smooth surface. Heated cylinders then dry the paper, and the finished paper is slit into smaller rolls.

Energy consumption is particularly high in pulp and paper mills and it is considered a key environmental issue in this sector (EIPPCB, 2001). The pulp and paper mills under study are energy self-sufficient, as almost all its energy requirements are satisfied by cogeneration units from biomass waste, black liquor, biosludge from wastewater treatment plants and fossil fuels, whilst 19% of total electricity requirements are purchased from the national grid.

The system under study (Figure 2.1) was divided into three main subsystems, which are briefly described below. As it can be possible observe in Figure 2.1, processes within the dashed area are those included in the study whereas the transportation to the customer, the use of the paper product and the end of life of the product is not under the system boundary. Moreover, infrastructure and maintenance of capital goods (buildings, materials, etc.) were also excluded due to the lack of data. In addition, in accordance with Jungmeier et al. (2002) for wood-based products, the

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[1] Stora Enso Oyj Veitsiluoto Mills, 2015. Personal communications.

differences are negligible compared to the overall environmental impact of the life cycle of the product.

2.1.2.1. Forestry

This subsystem includes all the operations carried out in Spruce and Pine stands in Finland: silviculture operations (site preparation, stand establishment and tending), logging operations (harvesting and forwarding) and transport from forest landing to pulp and paper mill gate by road vehicles (53%), trains (40%) and ships (7%). Spruce (Pices abies) and Pine (Pinus sylvestris) plantations were considered as they are the most common trees species both occurring almost all over the country (METLA, 2013). Seedling production was excluded due to the lack of data.

2.1.2.2. Pulp mill

This subsystem includes all the industrial activities related to pulp production which take place in the mill: Spruce/Pine timber debarking, chipping into regular size, digesting with H_2SO_4 and NaOH, pulp washing, pulp screening and refining primary (I), bleaching process (O_2, H_2O_2, $NaClO_3$ and chelating agent).

2.1.2.3. Paper mill

This subsystem includes all the industrial activities related to paper production which take place in the mill: pulp screening and refining secondary (II), forming, pressing, drying and finishing.

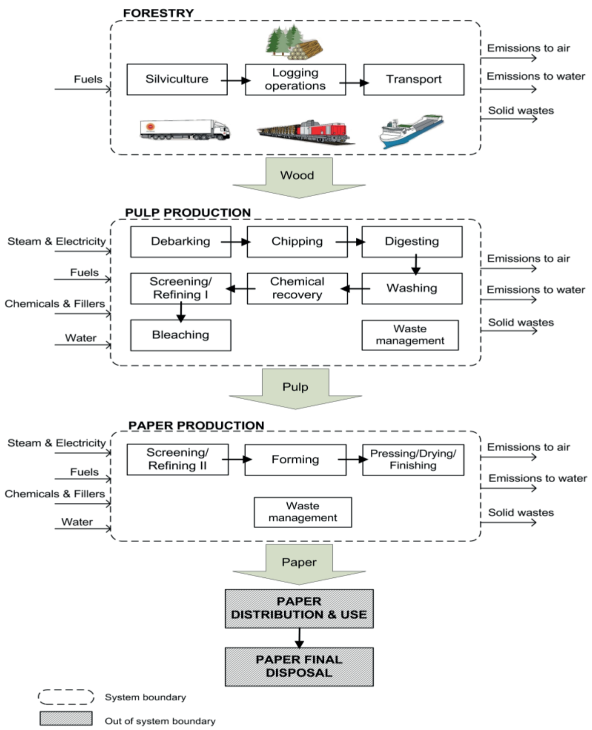

Figure 2.1: System boundaries and process chain under study.

2.2. Inventory analysis

Data were obtained from multiple sources. Interviews and company visits were completed with environmental declarations, internal company reports and bibliographic sources. Foreground data about the paper-making process and relative emissions were supplied by the Stora Enso company. Given the lack of data related to distribution of energy and water consumptions among process steps, an allocation was performed according to Giraldo & Hyman, 1996 and Brown et al., 1996. Data on the forest operations and emissions were obtained from the literature (Doherty, 1995; Karjalainen and Asikainen, 1996). Some background data, related to the use of electricity, auxiliary materials and impacts of the waste management have been derived from the Ecoinvent 3 database. In particular, for the supply of electricity required by process, the Finnish electric mix medium-voltage, was selected. Inventory data for the forestry and pulp and paper mill activities are shown in Table 2.1.

Table 2.1: Life cycle inventory. Values are referred to a functional unit of 1 ton of produced paper.

Materials & Energy	Unit	Value
Forestry		
Wood	m^3	2.00
Fuel	GJ	0.45
Transport by road	t-km	80
Transport by railway	t-km	141
Transport by sea	t-km	98
Pulp Production		
Electricity	GJ	0.81
Steam	GJ	6.30
Fuel	GJ	0.72
Water	m^3	34.18
Chemicals	kg	73.07
Paper Production		
Electricity	GJ	1.12
Steam	GJ	4.58
Fuel	GJ	0.07
Water	m^3	7.50
Chemicals	kg	352.95
Waste to treatment		
Wood and bark (reused)	kg	174.30
Sludge (reused)	kg	31.91
Dregs (reused)	kg	4.45
Ash (reused)	kg	10.41
Green Liquor Dregs (to landfill)	kg	1.02
Lime Mud (to landfill)	kg	0.38
Other Wastes (to landfill)	kg	1.28
Hazardous Wastes (to landfill)	kg	0.12

2.3. Environmental impact assessment

The Life Cycle Impact Assessment (LCIA) of the FU has been modelled with the SimaPro software version 8.0.5 (PreConsultant, 2014). The midpoint impact categories recommended by the ILCD Handbook (EC, 2010) have been selected for the LCIA. In particular, the impact assessment was performed by means of one of the most recent and up-to-date LCA methods, the ReCiPe method (Goedkoop et al., 2009). It provides characterization factors to quantify the contribution of processes to each impact category and normalization factors to allow a comparison across categories. In this study, the impact categories analyzed are: Global Warming Potential (GWP, kg CO_2 eq), Terrestrial Acidification Potential (TAP, kg 1,4-DB eq), Freshwater Eutrophication Potential (FEP, in kg P eq), Human Toxicity Potential (HTP in kg 1,4-DB eq), Photochemical Oxidation Potential (POCP, in kg NMVOC), Ionizing Radiation Potential (IRP, in kBq U235 eq), Water Depletion (WDP, in m^3), Metal Depletion (MDP, in kg Fe eq), Fossil Depletion (FDP, in kg oil eq).

3. Results and discussion

Table 3.1 summarizes the characterized impacts calculated by applying the ReCiPe Midpoint (H) method to the pulp and paper mill complex of Stora Enso Oyj Veitsiluoto Mills, with reference to a functional unit of 1 ton of produced paper. For each impact category, the impacts generated by the forestry phase are negligible, being always less than 10% of the total impacts except for the case of POFP, where the contribution of the forestry phase reaches the 14%. The processing steps of the paper production phase impact more on TAP, POFP and WDP, respectively with 4.27 kg SO_2 eq, 2.83 kg NMVOC and over 3224 m^3 *versus* 3.38 kg SO_2 eq, 2.52 kg NMVOC and 3050 m^3 generated from the pulp production phase. In the remaining impact categories, the pulp production phase is responsible for the major contributions, ranging from 48% of the total impact in FDP up to 60% in FEP.

Table 3.1. Recipe Midpoint (H) characterized impacts calculated for the pulp and paper mill, referred to a functional unit of 1 ton of produced paper.

Impact category	Unit	Total	Forestry phase	Pulp production	Paper production
GWP	kg CO_2 eq	1637.61	80.89	816.00	740.72
TAP	kg SO_2 eq	8.17	0.51	3.38	4.27
FEP	kg P eq	0.34	0.01	0.20	0.13
HTP	kg 1,4-DB eq	315.32	6.34	184.88	124.09
POFP	kg NMVOC	6.25	0.89	2.52	2.83
IRP	kBq U235 eq	332.96	6.20	172.86	153.89
WDP	m^3	6326.59	51.62	3050.62	3224.35
MDP	kg Fe eq	32.86	3.07	17.13	12.66
FDP	kg oil eq	500.68	22.18	242.61	235.89

If normalized values of impacts are taken into account (Figure 3.1), according to Europe ReCiPe Midpoint (H) method normalization factors, a comparison across impact categories becomes possible (water depletion category is not detectable at all, due to the normalization factor equal to zero, and it is not shown in the Figure). The most highly impacted category results to be FEP, followed by HTP and FDP, with normalized impacts respectively amounting to 0.8150, 0.5014 and 0.3219, mainly generated from the pulp production phase.

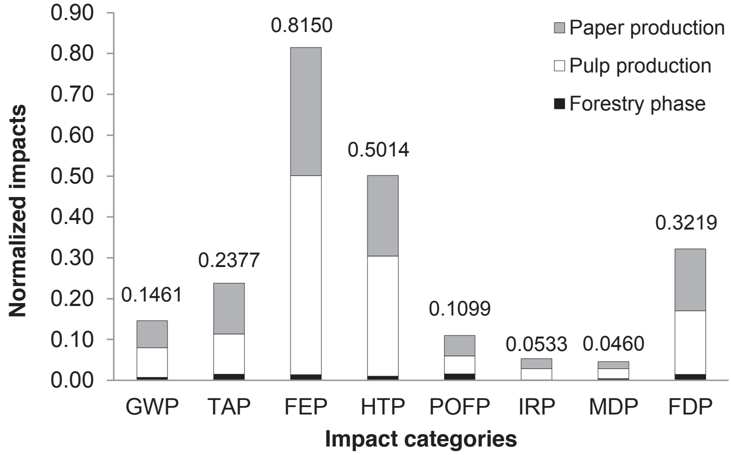

Figure 3.1. Recipe Midpoint (H) normalized impacts calculated for the pulp and paper mill, referred to a functional unit of 1 ton of produced paper.

In order to have a deeper insight into the pulp and paper production phases, Figures 3.2 and 3.3 respectively show the breakdown of the impacts generated by different steps of the production process.

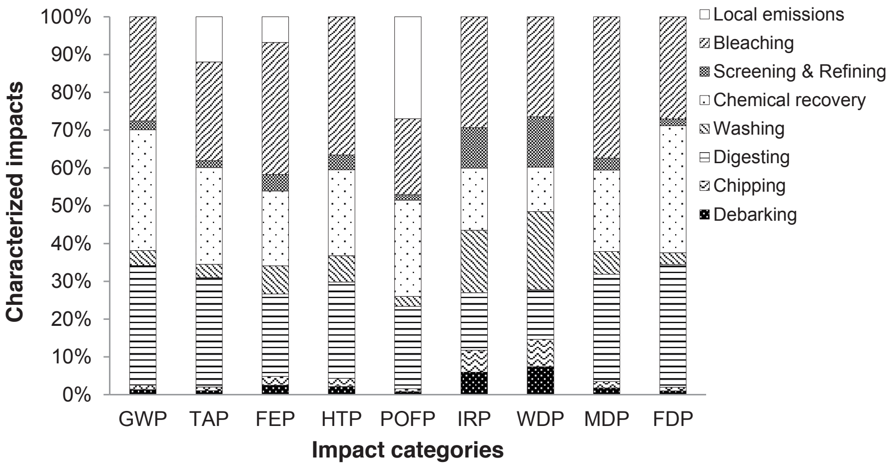

Figure 3.2. Breakdown of Recipe Midpoint (H) characterized impacts for different steps of the pulp production phase, referred to a functional unit of 1 ton of produced paper.

Concerning the pulp production phase (Figure 3.2), all the impact categories are mostly affected by digesting, chemical recovery and bleaching steps, that together are responsible for more than 90% of impacts generated on GWP and FDP and more than 80% of impacts generated on TAP, HTP and MDP, generally due to the amount of electricity and heat required. In particular, the digesting step impacts on TAP with 0.98 kg SO_2 eq, the step of chemical recovery generates negative effects on GWP, POFP and FDP producing 261 kg CO_2 eq, 0.64 kg NMVOC and 82 kg oil eq,

whereas the remaining impact categories (FEP, HTP, IRP, WDP, MDP) are mainly affected by the bleaching step, in the amounts of 0.071 kg P eq, 68 kg 1,4-DB eq, 51 kBq U235 eq, 807 m^3 and 6.4 kg Fe eq.
As shown in Figure 3.3, the very last processing steps (pressing/drying/finishing) of the paper production phase represent the largest share of impacts in all investigated categories, ranging from 66% in FEP up to 91% in FDP, except for IRP and WDP where their contribution represents 46% and 43% of the total impacts and forming, screening and refining steps together determine the major impacts. In this case, the generated impacts are attributable not only to the energy requirements, but also to the optical brighteners and fillers used in the finishing step.

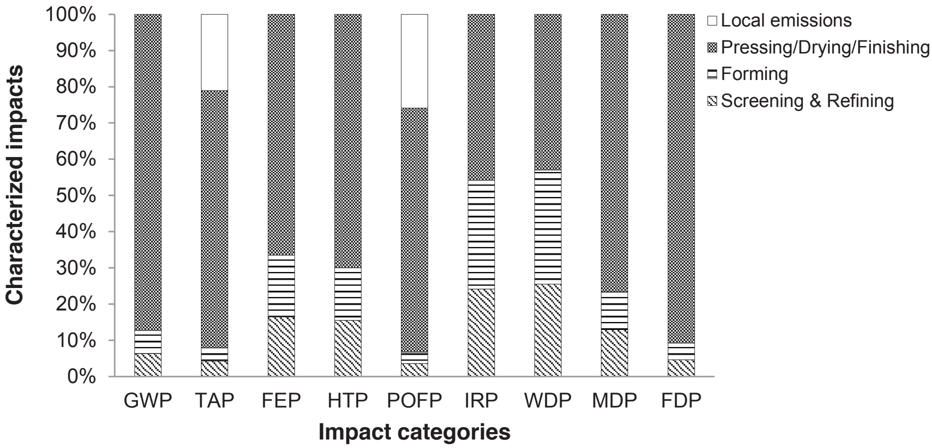

Figure 3.3. Breakdown of Recipe Midpoint (H) characterized impacts for different steps of the paper production phase, referred to a functional unit of 1 ton of produced paper.

A significant improvement in the environmental performance of the production process is achieved if the energy requirements of the plant are fulfilled by producing heat and electricity *in situ* from the available residual biomass, option that the pulp and paper mill under investigation already implemented partially (only 290 kWh/ton of produced paper are purchased by the plant as electricity). As shown in Figure 3.4, a reduction equal to or greater than 70% of impacts is obtained in GWP, FEP and FDP and of 66% in HTP. In the case of IRP, the production of electricity and heat in the plant itself results in a saving of ionizing radiations (negative value of the impact), as a consequence of the avoided supply of electricity from conventional routes (including nuclear energy as well).

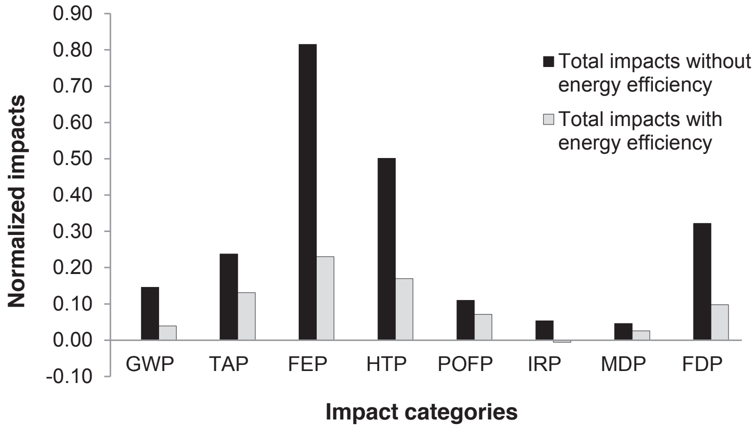

Figure 3.4. Recipe Midpoint (H) normalized impacts without and with energy efficiency implementation, referred to a functional unit of 1 ton of produced paper.

The unresolved impacts are due to the chemical products utilized in the whole papermaking process and to the transport and energy requirements involved in background processes. The use of renewable sources of energy resulted to be crucial in lowering the environmental burdens and, therefore, further benefits may derive from an enhanced recovery of resources and from the implementation of material and energy efficiency.

4. Conclusions

In this study the LCA method was applied to paper manufacturing process in Finland in order to identify those process steps that entail the highest environmental loads and require improvements. The results show that the most relevant stages in environmental costs are due to pulping operations related to high chemicals and energy consumption while the forestry activities play a minor role on the whole process. To reduce the overall environmental burden, optimizing electricity, chemicals, and water consumption efficiency, and changing the end-life treatment of solid waste from landfill to incineration are highly recommended.

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Bioeconomy and the challenge of community centred design

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Abstract

The development of the bioeconomy shows great promises for the transition to a more sustainable society, but it is still controversial due to the many risks, pitfalls, and uncertainties that accompany its potentially very large socio-economic benefits. The debate on the bioeconomy tends to be characterized by a polarization between proponents and critics, but many of these controversies will likely not be resolved through more science, as fundamental differences in value and paradigm are involved, even in the scientific disputes themselves. On the other hand the social acceptance of newly emerging technologies is of crucial importance to their success and the engagement of the public at the level of technology-in-the-making may prove to be highly beneficial for the technological development itself, reducing the risks associated with the innovation process. The paper focuses on the involvement of local communities as strategy to increase the social acceptance of prototypal and industrial plants in the field of the bioeconomy. An overview of current main societal issues and challenges is provided, reviewing roles, scopes, values and needs of all involved parties. Furthermore, barriers to the effective community centeredness for bioeconomy stakeholders and the whole society is discussed. Key principles for the effective communication, sensitization and participation of local communities are surveyed, together with the role of Responsible Research & Innovation and trustworthiness on the research and industry side. Finally, a framework and techniques to set an effective community-centred siting process for bioeconomy facilities are discussed, providing key references for the application of methodologies from user centred design and design thinking approaches.

1. The issue of social acceptance of bioeconomy industry

The development of the bioeconomy shows great promises for the transition to a more sustainable society, but it is still controversial due to the many risks, pitfalls, and uncertainties that accompany the potentially very large socio-economic benefits (Kornerup Bang et al., 2009). According McDonagh (2015) “there is little consensus on what the bioeconomy is or what it does or does not include”. A rather clear definition of the concept of bieconomy comes from European Commission documents and policies since 2012, when a strategy for “Innovating for Sustainable Growth: A Bioeconomy for Europe” was published providing an overall definition and overview of the bioeconomy. According the European Commission (2012) the bioeconomy “encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy [and] includes the sectors of agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries”. A relevant aspect of the bioeconomy is that it encompasses a broad range of activities, situated along a multitude of different value chains, each including suppliers, producers, distributors, and purchasers (Gołebiewski, 2013).

As the debate on the bioeconomy tends to be characterized by a polarization between proponents and critics (Hansen, 2012), the desirability of such an economy arises a wide spectrum of attitudes among stakeholders (Schuurbierser et al., 2007). Many of these controversies will likely not be resolved through more science, as fundamental differences in value and paradigm are at play, also in the scientific disputes themselves (Hansen, 2012; Sarewitz, 2004). Therefore, also OCED (2009) considers the societal engagement with the bioeconomy a key factor for the full unleashing of such economy promises of sustainability, invigoration of agricultural practices and production, and economic opportunities for all stakeholders. Moreover, especially in European Union where bio-based industry has been officially recognized as a key trajectory for research and industrial leadership, social legitimacy is sought as many public funds are invested in research and development programmes on the bioeconomy (Asveld et al., 2011).

The public acceptance of newly emerging technologies is of crucial importance to their success (Felt & Wynne, 2007; Soetaert & Vandamme, 2006); in the framework of the bioeconomy it has to be considered that public policies aligning economic interests of the industry with the values and needs of society at large depend on a well-informed, engaged, and balanced societal debate and societal engagement at large (Paula & Birrer, 2006; Pierce, 2012). According Edelstein (2004), "*there are compelling personal reasons for opposition to a specific project on a specific site. Facilities may generate noxious odours, visual intrusion, noise, traffic, perceived contamination, or some other limiting conditions that alter victims' lifestyle , the core activities of their daily lives. There may be additional threats to lifescape , challenging victims' core life assumptions of health, control, security of home and community, and trust of the environment and social and institutional networks. Additional abstract reasons for opposition include questioning need for the facility, recognizing better alternatives, or identifying cumulative impacts*."

Many authors (i.e. Schuurbiers et al., 2007; Soetaert & Vandamme, 2006) state that the engagement of the public at the level of technology-in-the-making could be highly beneficial for the technological development itself, also reducing the risks associated with the innovation process. It is acknowledged (Hasenheit et al. 2016) that there is a wide range of positive and negative impacts of bioeconomy products and processes that may affect people, regions and countries in different ways. For what concerns bioeconomy research and development activities and related industrial exploitation, a series of common pro & cons claims can be identified, at both local and global scales (Burningham, 2000). Positive aspects that are acknowledged at local scale include, in example, the potential of local development and new jobs creation in remote rural areas, bio remediation possibilities for polluted soils, the possibility to deliver more public services and infrastructures or tax reductions also thanks to the revenues. On the other hands, benefits form bioeconomy at global scale are related to the reduction of Green House Gas (GHG) emissions and the use of renewable feedstock. Contrary positions towards bioeconomy in local communities are based on the risk of water contamination and health, safety and security risks, on the fear of traditional job losses or the worry about the depreciation of urban and rural areas due to smell of pollution. Furthermore, opposition to bioeconomy for its impact at global scale concerns land-grabbing, the competition among food and fuel farming, the loss of biodiversity, the role of multinationals in patenting, the unfair distribution of benefits, the potential misuse of bio-based technologies; it is also argued that the production of biofuels support the existence of carbon intensive transport systems (Hasenheit et al., 2016). Literature on siting of many kind of "sustainable" facilities discusses the phenomenon that certain services are in principle considered as beneficial by the majority of the population, but that proposed facilities to provide these services are in practice often strongly opposed by local residents (van der Horst, 2007), as their siting is commonly thought of as an act of inherent violence to place and community (Edelstein, 2004).

2. A framework for stakeholders cooperation

Community opposition to stigmatized facilities represents a challenge for new sustainable technologies that demands some form of collective action to be solved (Edelstein, 2004). This is sought in order to overcome the social gap' between the need and support for sustainable technologies from public side and the local opposition that frequently occurs when a specific project is proposed (Bell et al., 2005). This situation requires a tradeoff based on the elicitation of dissensus and conflict resolution techniques to bridge the diametrically opposite evaluations of the same project hold by opponents and advocates (Beck, 1992). First step to achieve an effective participation process is the setting up of an adequate communication process, in order to facilitate and finalize the communication among all the many stakeholders involved in bioeconomy. Communication is based on sources emitting a message and receivers of that message; emitting sources in a debate about bioeconomy facilities are from both bioeconomy side (researchers bringing discussing actual benefit of a given plant; industry willing to demonstrate the benefit for the environment, the economy and the society from such kind of facilities) and community side (consumers' associations, policy makers and non-governmental organisations that might argue either pro either cons positions). On the other side, all the stakeholders are message receivers: individuals, consumers' associations, policy makers, NGOs, researchers, industry. For what concerns industry, it has to be considered that communication flows relate to either bioeconomy industries towards/from other types of stakeholders either bioeconomy industry towards/from industries from other industrial sectors. In this framework, a clear communication is an ambitious goal, as it touches values, concerns and needs of all involved parties and its effectiveness depends on:

- possible gaps in knowledge levels (i.e. general vs technical and scientific education)
- the attitude towards science & technology (i.e. nature, environment, research exploitation)
- beliefs and worldviews (i.e. about distributional justice, capital intensive industry vs local knowledge & capability, selfishness/altruism)

that have to be taken into account to better accommodate diversity and complexity (A De Witt et al, 2015; Ganzevles et al , 2015; Asveld et al, 2015).

In order to overcome these potential communication barriers, there are some communication basics for science and technology topics[1] that should be taken into account by bioeconomy promoters to start-up a community-centred process when planning a facility, that are (Peters, 2013):

- defining the audience

[1] https://www.aaas.org/page/communicating-engage retrieved on line January 24 2017

- choosing the right words
- choosing supporting information and visualizations
- developing the message
- avoiding communication interferences due to neglecting
    - audience's values, needs and concerns
    - the lack of common experiences and language
    - unclear scopes and willingness.

The above recommendations represent the first step to build a process leading all involved parties to the awareness about mutual needs and, finally, to the delivery of a community centred plan for new bioeconomy facilities. In this path, it can be useful to keep in mind what communities seek in science and technology side for the bioeconomy plants are accepted. In this perspectives, three key concepts provide a reference framework to foster the cooperative approach among all stakeholders: Responsible Research & Innovation, Engagement, and Trustworthiness.

The concept of Responsible Research & Innovation (RRI) refers to transparent, interactive process where societal actors and innovators become mutually responsive to each other, thanks to a shared view on ethical acceptability, sustainability and societal desirability of the innovation process and its marketable products. Then, RRI concerns the introduction of technologies that touch upon socially sensitive issues, the identification and accommodation of public concerns when developing a new technology, the engagement with a wide range of relevant actors (Von Schomberg, 2011). RRI approach triggers interactive and transparent process that foster best conditions for trustworthiness among actors in the relevant value-chain (Asveld et al., 2015). Since bioeconomy requires changes in the social structures embedding bioeconomy manufacturers, suppliers, policymakers, citizens, trustworthiness is crucial to set-up the collaboration between actors that did not previously co-operate (Asveld et al. 2011; Bos-Brouwers et al. 2012). Therefore, bioeconomy implementation requires the 'mutual responsiveness' of actors in order to become active players in the bioeconomy; engagement is then a core dimension also for the implementation of RRI. In fact, community engagement helps to handle socially sensitive issues that need to be addressed to make bioeconomy facilities welcomed by local communities (Asveld et al. 2011; Bos-Brouwers et al. 2012). Citizens engagement, or community participation, is based on laying people in decision making (inclusion), on the systematic thinking aimed at increasing resilience while revealing new opportunities for innovation (anticipation), on demanding actors to critically assess their own preconceptions (reflexivity), and on willingness to adapt an innovation to societal response (responsiveness) (Stilgoe et al. 2013; Owen et al. 2012). Community engagement since early stages of the planning of a bioeconomy facility is crucial for the trustworthiness among the involved parties. New technologies associated with the bioeconomy bring about risks and uncertainty and actors will only accept such risks and uncertainties if they trust the parties that control the relevant technologies (Asveld et Al 2015). Trust is the decision of one party to rely on another party under conditions of risk, it cannot be brought about in another person but it is possible to create conditions for trust. In the case of bioeconomy, advantages are difficult to observe, not directly perceptible by most individuals and rely on the testimony of other actors, and bio-economic innovations can have a considerable impact on the environment of people's homes. On the other hand, new social alliances needed for the bioeconomy success involve new risks and concerns but actors have no other grounds to assess each other's trustworthiness because they do not know, so mutual understanding of each other's values, reasons and perspectives is a key factor for bioeconomy development and deployment.

3 A possible approach for community centeredness in bioeconomy

Many authors state that adequate participation processes can reduce conflict in the planning process (i.e. Zhang, 2015; Innes and Booher,2004) and this can be achieved by "devising procedures to facilitate quick and efficient negotiations" (Cohen et al.,2014). In addition to common quantitative approaches as surveys and forums (van der Horst, 2007), there is a clear need for more in-depth qualitative research (Cowan, 2003) to better understand specific concerns of local communities and improve the consideration of social issues into the sustainable facilities design process.

In this perspective, the reference to contexts and techniques focused on people needs, people desires and people engagement can provide all interested parties with the most appropriate tools to foster communication, trustworthiness, responsibility and responsiveness in the planning process of bioeconomy facilities. The rather wide field of user-centered design (UCD) represents a reference framework to implement such approach in the bioeconomy domain, as it is based on the consideration of people characteristics and needs and their involvement into the whole design process (Martin and Hanington, 2012). Among the many applications of UCD, Design Thinking (DT) brings specific approaches particularly relevant for the outreach and engagement of local communities involved in bioeconomy projects. In fact, its specific techniques allow to identify known and ambiguous aspects on a context or situation, unveiling hidden parameters and alternative paths to the goal (Brown, 2009). DT is able to mediate among social expectation and needs and the feasibility of solutions, to identify expectations and unmet needs and, finally, to identify constraints relevant for communities at the earliest stages of a project (Goodman, 2012). Typical Design Thinking techniques applicable in the field of bioeconomy are listed in Table 1 (Duca, 2014), together with a brief description and resulting outputs that helps all stakeholders to mutually understand and to collaborate to achieve the most acceptable bioeconomy project for a local community.

Table 1: Application of UCD/DT techniques in the bioeconomy field

UCD / DT technique	Technique description	Resulting outputs feeding the community centred design process
Card Sorting	Ask people to organize items into groups and assign categories to each group	Hierarchize values and needs
Focus Groups	Groups of 3-12 participants are lead through a discussion about a set of topics, giving verbal and written feedback through discussion and exercises	Structured confrontation among stakeholders
Individual Interviews	A researcher meets with participants one-on-one to discuss in depth what the participant thinks about the topic in question	Deepen aspects related to values and beliefs
Desirability Studies	Participants are offered different alternatives and are expected to associate each	Elicit pro and cons of alternative solutions

UCD / DT technique	Technique description	Resulting outputs feeding the community centred design process
	alternative with a set of attributes selected from a closed list	under the perspectives of different stakeholders
Personas	Creation of a set of representative user based on available data and user interviews. Though the personal details of the persona may be fiction, the information used to create the user type is not	Foresee possible reactions, transfer adequately technical and scientific information
Surveys	A series of questions asked to multiple persons and stakeholders help you learn about the community to engage	Understand the impact of a project on a community at a wider scale
Visualization of the project	Rendering, virtual reality tour, open days in similar plants	Reinforce trustworthiness and responsiveness among the parties

4 Conclusions

In this paper the relevance of the acceptance by local communities of bioeconomy plants to achieve the expected benefits for the whole society has been discussed. Bioeconomy generates new links and relationships among social actors that were not requested to communicate and cooperate before, and this leads to conflict situations that need specific methodologies and know-how to ensure the full sustainability of bioeconomy plants and projects also under the social and economic perspective (Aaen et al, 2016). In this view, techniques from UCD and, namely, from Design Thinking can be considered a key approach to engage communities, to gather needs and requirements from involved stakeholders and to build real value chain from new available bioeconomy technologies. But also if specific DT know-how is made available, the challenge to harmonize communities and bioeconomy can only be met if user centred designers are sure that all parties are sitting at the table, invited representatives are actually and still representative of given involved groups, the scale of the project is clearly understood by the audience, research & industry side are truly willing and responsive, human centred design skills are on board since early stages of the project.

End note

This paper is the result of a collective work, but, for the proposes of this publication, G. Trupiano wrote paragraph 1, G. Duca wrote paragraphs 2 and 3, authors wrote together paragraph 4.

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Energy performance at city level − the societal metabolism of Barcelona

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Abstract

Cities are the engine of economic development but their dynamics need to be supported by the convergence of large flows of material and energy resources. According to the UN World Urbanization Prospects (2014), 54% of the world's population resided in urban areas in 2014, and this figure is expected to reach 66% by 2050. Although cities presently cover less than 2% of the earth's surface, they consume about 78% of the energy under human control, to which one must add the amount of material products (food, building materials, metals, etc.) that indirectly require energy consumption. Many cities have pushed out their industries to their metropolitan areas or to remotest regions becoming basically services cities. Many infrastructures shape and characterize the urban metabolism, as well as the mix of service activities taking place inside the city or the heterogeneous residential sector within the city. Even more challenging is the fact that many activities of a city are carried on by people (commuters, tourists) that do not live in it. This fact poses an epistemological challenge when coming to defining the boundaries to be considered for metabolic analysis (who is consuming energy to do what). In the present paper we present an innovative analysis of Barcelona energy metabolism, a global city characterized by the importance of its service sector, especially for tourism. For this analysis, we use the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), an innovative tool capable of analyzing biophysical flows/fund relations by characterizing the energy metabolic pattern of the different functional sectors and neighborhoods of the city. The tool can be used both in diagnostic mode or simulation mode to have a better informed discussion about hot topics such as energy efficiency, energy poverty, energy transition, or energy democracy. This study was developed as part of a broader project Euforie (European Futures for Energy Efficiency), founded by EU in 2015, with the goal of developing a tool capable of characterizing how different forms of energy carriers are used to perform different societal tasks – i.e. end-uses - (industrial production, mobility, tourism, residential, commercial activities, etc.). The proposed approach allows looking for potential conflicts among these end-uses in the case drastic measures of de-carbonization may limit the supply of the required energy inputs.

1. Introduction

Cities are the centre of the economy and power of nations. In 2014, 54% of the world population was reported to live in urban areas and, according to UN projections, it could reach 66% by 2050 (United Nations, 2016). Cities are the places where higher value added activities are developed, already accounting for 80% of the world's GDP in 2013 (OECD 2016). Cities are socio-ecological systems – SES - (Odum, 1971; Rosen, 1991; Tainter, 1988) that are in constant evolution and interact with their smaller parts and the external systems in a nowadays worldwide network. From a thermodynamic perspective, cities represent open systems, constantly importing and exporting energy and matter across their boundaries (Nicolis and Pricogine, 1977).
Globalization highlights the openness of urban systems: choosing between domestic and foreign products, living with foreign neighbours or looking for a job abroad, exchanges of information through communication technologies. Fossil-fueled transport and the more recent advances on telecommunications have created a globalized and international division of labor and reshaped cities worldwide. Nicolis and Prigogine (1977) noted that a city "can survive as long as it is the inflow of food, fuel and other commodities and sends out products and waste", and cities are increasingly bringing

these inputs from further so they can devote their human capital to other activities. In fact, the maximum economic power is represented by a group of global cities with transnational corporate headquarters, finance and IT centres, news offices, information and entertainment services, and Barcelona is considered one of them (Sassen, 2010). Also, these increased mobility options make that many activities of a city are carried on by people (commuters, tourists) that do not live in it. This fact poses an epistemological challenge when coming to defining the boundaries to be considered for metabolic analysis (who is consuming energy to do what).
At an urban level, the industrial revolution and the modernism in urbanism have enhanced the plurality of functions that a city can perform, generating areas devoted to different and single activities (López de Lucio, 1993). The city, then, works as a conglomeration of organs that have been adapted to perform a specific function and that, interacting, create an emergent property ("the whole is greater than the sum of its parts") (Von Bertalanffy, 1972).
Thus, as living organisms, cities have metabolism. The "metabolism of human society" is a notion used to characterize the processes of energy and material transformation in a society that are necessary for its continued existence. This notion became a scientific subject starting the mid-19th century because of the work of authors such as Liebig, Boussingault, Moleschott, Jevons, Podolinski, Arrhenius, Ostwald, Lotka, White, and Cottrel (for an overview, see (Martinez-Alier, 1987)).
The proper accounting of urban metabolism is of paramount importance when policy plans aiming at energy efficiency and climate mitigations strategies (e.g. PMEB - Barcelona Energy Improvement Plan , PECQ, - Pla d'Energia Canvi Climàtic i Qualitat de l'Aire de Barcelona (Ajuntament de Barcelona, 2011), COM, Covenant of Mayors performance) come into play.
The analysis of the metabolic pattern of a social-ecological system has to be first framed in semantic terms and then formalized in quantitative assessments using an integrated set of metrics (different categories of accounting). Therefore, the analysis of the metabolic pattern has to start with the identification of the metabolic characteristics of its functional elements and their forced relations. To understand better this task let's start from the definition of "a system" and apply to this definition the wisdom of relational analysis.

A system is a set of functional and structural components linked by some form of interaction and interdependence operating within a given boundary ***to achieve a common final goal*** *(a given final cause)*.

The final cause of a complex system, as a city, is the "emergent property" of the system: it is what makes "the whole" meaningful and more than the sum of its parts. In the case of an analysis of urban metabolism the emergent property of a city is its ability of reproducing, maintaining and adapting its identity in time. Adopting an impredicative definition – typical of self-producing and adaptive systems – we can say that the identity of the city is associated with the ability to preserve and adapt the meaning of the identity of the set of functional and structural elements composing it.

The narrative of urban metabolism – the integrated set of material and energy flows that have to be metabolized to preserve and adapt the identity of the city - can be used to provide the rationale for: (i) identifying the functional and structural parts of the metabolic pattern; and (ii) studying the relations over them.

***A city** is composed by a set of functional and structural components **operating in the technosphere** (processes under human control) within a prescribed boundary. The goal of a city is that of reproducing and maintaining its identity (the identity of the whole) while learning how to become more adaptable. The functional components of a city are linked through a pattern of expected interactions determining a dynamic interdependence over their identities (defined at hierarchical level lower than the one of the city). The possibility of stabilizing the metabolic flows consumed and generated by a city depends on the existence of other processes **operating in the biosphere** (processes outside human control) determining the required supply and sink capacity.*

Therefore, in this paper, MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) is used to analyze the urban metabolism in Barcelona by identifying across different hierarchical levels of organization: (i) the whole with its boundary; (ii) the functional compartments; (iii) the functional elements of the functional compartments; (iv) the structural elements operating in the functional elements, that can be used as external referent to study their metabolic characteristics.

2. Materials and Methods

2.1. MuSIASEM framework

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) (Giampietro, 2003; Giampietro et al., 2013, 2012, 2009, 2006, Giampietro and Mayumi, 2000a, 2000b, 1997; Giampietro and Sorman, 2012; Pastore et al., 2000; Ramos-Martin et al., 2007; Sorman and Giampietro, 2011) is a quantitative tool to analyze socio-economic systems using simultaneously technical, economic, social, demographic and ecological variables. MuSIASEM builds on the flow-fund model of Georgescu-Roegen (1971) as well as on complexity theory and autopoietic systems theory (Maturana and Varela, 1998, 1980, Ulanowicz, 1997, 1986).
In order to define the metabolic pattern of human societies we must define "what the system is" and "what the system does", which Georgescu-Roegen (1975) defined as fund and flow elements, respectively. Funds (capital, labor, available land) are agents that enter and exit the process, transforming input flows into output flows. They preserve their identity over the given period of analysis and must be periodically renewed, and the maintenance of these funds is the basis of sustainability. Flows (energy, products, money) are elements that enter but do not exit the production process, or that exit without entering. Flows and funds are related: the sizes of the various flows are determined by the characteristics of the various processes taking place inside society and, in turn, these processes are determined by the combination of the size and the metabolic characteristics of the fund elements metabolizing the flows. Thus, at a practical level, any flow of energy (a quantity per year in MJ or kWh) must always be associated with the size of a fund element (a structural element used as external referent as hours of human activity or m^2 of land use), in order to have the metabolic characteristic of the fund element: the pace (MJ/h) or the density (MJ/ m^2).
The link between a quantity of energy consumed and the metabolic process associated is important because it establishes an accounting scheme across different hierarchical levels. These ratios can be compared between levels or also against reference values (benchmarks) describing known types of socio-economic systems. The information on extensive variables comes from statistical sources (top-down), whereas the one on the paces or densities are available as technical characteristics of structural elements

(bottom-up). The parallel use of these two sources of information generates redundancy in the information space (the so-called Sudoku effect (Giampietro and Bukkens, 2015)) which allows triangulating. Each hierarchical level (shown in Figure 3) is described by an array of intensive and extensive variables defined in relation to quantities calculated on a year basis as in the following:

Ext. var.		Intensive variables								Extensive variables			
HA	**BU**	**EMR_{elec}**	**EMR_{heat}**	**EMR_{fuel}**	**EJP**	**EMD_{elec}**	**EMD_{heat}**	**EMD_{fuel}**	**EBUP**	**ET_{elec}**	**ET_{heat}**	**ET_{fuel}**	**VA**
Funds		Flow/Fund								Flow			

Where:

Table 1: Indicators used in the MuSIASEM of Barcelona
(intensive variables are averages per year)

Indicator		Definition	Unit
HA	Human Activity	time invested in the end-use per year	h per year
BU	Building Use	quantity of area devoted to the end-use	m^2
EMR_i	Exosomatic Metabolic Rate	ET_i/HA: amount of energy carrier *i* metabolized per hour of work allocated to the end-use	kWh/h or MJ/h
EJP	Economic Job Productivity	VA/HA: value added per hour of working time of end-use	€/h
EMD_i	Energy Metabolic Density	ET_i/BU: amount of energy carrier *i* metabolized per m^2 of building area devoted to the end-use	kWh/m^2 or MJ/m^2
EBUP	Economic Building Use Productivity	GVA/BU: value added per area of end-use	€/m^2
ET_i	Energy Throughput	Amount of energy throughput metabolized in the form of energy carrier *i* (electricity, heat or fuel) by the end-use.	kWh or MJ per year
VA	Value Added	Value Added of goods and services produced by the end-use	€/year

2.2 System description

Barcelona is the second biggest city in Spain and capital of Catalonia, located at the north-east of the Iberian Peninsula, limited at the east by the Mediterranean Sea and at west by the Collserola Mountain. With a population of 1,604,555 inhabitants in 2012 and occupying 102.16 km^2, it is one of the densest cities in Europe. It is divided in 10 administrative districts and 73 quarters ("barrios") (Ajuntament de Barcelona, 2012). The demographic structure of the city is the typical for a developed country (Figure 1), with an ageing population and an important flux of immigrants since the 1990s. Representing a 21.2% of the population and a 34.6% of the GDP of Catalunya, it is the center of a bigger metropolitan area (AMB) with some administrative functions, most of its population living in the urban agglomeration around Barcelona. The AMB had 3.299.337 inhabitants in 2012, and an important number of them commute every day from and to Barcelona (Àrea Metropolitana de Barcelona, 2012). Commuting takes place not only by car, since the city offers a wide supply of public transport (buses, metro, tram, traint, etc), connecting the different municipalities in the AMB to the city through a radial infrastructure.

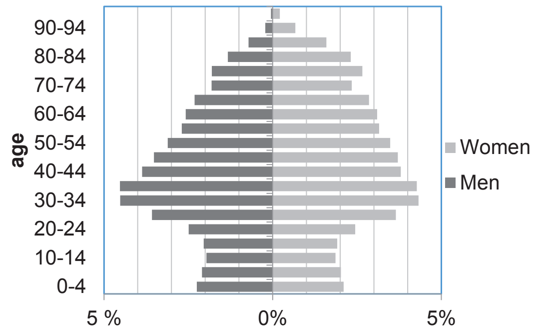

Figure 1: Demographic structure of Barcelona, 2012

2.3 Hierarchical organization of relevant economic sectors and subsectors

The boundary chosen for this study was the physical limits of the city including all the activities happening inside. The choice of the set of compartments is flexible; compartments may be aggregated or further disaggregated depending on the issue of interest, provided that the closure requirement is observed – i.e. the sum of the size of lower level compartments must sum up to the size of higher level the compartments. The hierarchical organization of the system of Barcelona is shown in Figure 2. First of all, the city of Barcelona (level n) is divided into two functional compartments (level n-1): paid work (PW), which generates value added, and the household sector (HH), reproducing individuals. n-2 inside HH we have two parts: residential (RES) (what happens inside the households) and private transport (MOB) (motorized private transport used outside of the paid work). The residential sector is further divided at n-3 level in the ten districts and at n-4 in the 73 “barrios”. At the level n-3 inside mobility there are two structural elements: cars and motorbikes.
It is important to note that the definition of functional elements is necessary to identify how to account the flows of energy metabolized by the structural elements. People living in residential buildings, vehicles moving in Barcelona, shops, installations and cruisers in the port, etc. (structural elements of Barcelona) are the external referents for the assessments of energy metabolism – they define the pace or the density of energy flows. Then the trip of a given model of a car – the external referent for fuel consumption – can be accounted in the household sector, if the car is used by a private or in the service sector if it is used as a taxi. The same criterion applies for the electricity consumed by an air-conditioner when used in a house or in an office.
Within the paid work sector two large sub-sectors and two functional elements are considered: Services and Government (SG), Manufacturing and Construction(MC), the port and the Energy Sector (ES). As the agricultural primary sector is negligible in the economy of the city, it is not considered. The port is included at the level n-2 due to its special key function: connecting the city at a global scale with the imports of energy, food and other products, and the exports of some manufactured products from the local industry.
Inside SG at the level n-3, there are activities related with transport, and sub-sectors (commerce, offices, education, healthcare, hotels bars and restaurants, and other) which at the level n-4 are organized by barrios.

Further details regarding the calculation procedures will be provided in the full paper.

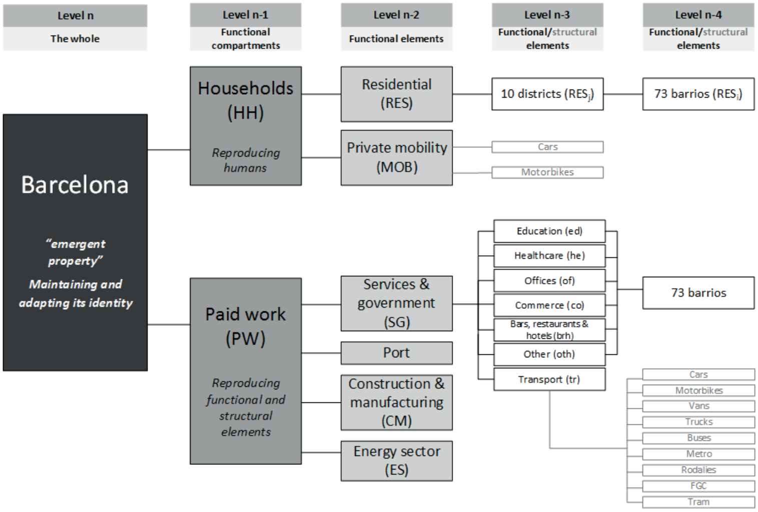

Figure 2: Hierarchical organization of relations over functional and structural elements for the accounting of metabolic flows in Barcelona.

3. Results and Discussion

The results of the analysis are here summarized in two tables. Due to the limitation of space, the results of levels n-3 and level n-4 are not shown here. Nonetheless, they will be reported in the full paper.

3.1 Level n, n-1, n-2

Table 2 shows the array of values (extensive and intensive) expressing the flows of energy carriers (electricity, heat and fuel) and value added produced by the different hierarchical (functional) compartments of the city, whose size is determined by the HA (i.e. human time). Table 3 presents the array of values (extensive and intensive) expressing the flows of energy carriers (electricity, heat and fuel) and value added metabolized by the different hierarchical (functional) compartments of the city, which are here sized depending on the building area in use (BU).
In both tables, each level can be described using extensive variables – the quantity of either fund and flow elements averaged over a year, representing their "size" - or intensive variables (expressed as the ratios between flows and funds, e.g. kWh/h), expressing the pace and density.
The BCN level (city), our focal level (n), accounts for the total amount of flows consumed by society and the total funds that have to be reproduced in a city. As already shown in previous analyses, HA in HH represents around 90% of total HA. The largest share of HA_{PW} is allocated to the SG sector, which has the largest metabolic ratios (EMD_{el} and EMR_{el}) for electricity and the lowest for heat. In developed countries, the household sector (human activities outside of paid work) and the services sector (private and public services) are considered as net consumers of biophysical flows (i.e. bio-economic pressure), which must be supplied by the primary and secondary sectors. The energy sector has especially high metabolic ratios, and at the same time, a low HA and BU. This is in line with the fact that in Barcelona has only one power plant within its boundaries contributing only partially to the electricity supply of the city. Apart from this traditional classification of sub-sectors there's the port, which has a

special behaviour, with high EMRs and EJP but at the same time lower EMDs and EBUP than the other sectors in PW. These values can be explained by the use of large machinery and ships, the little work associated to it and the need of space to store and move the goods. The existence of this infrastructure is neither significant only in monetary terms, since it is the piece of the system that allows international shipping both for exports and imports of energy, food and products whose production has been externalized, nor from a city perspective, since it provides services to the whole hinterland.

Table 2: End-use matrix, including EMRs and EJP, of the main levels of analysis (n, n-1, n-2) in Barcelona, 2012

	HA	**EMRs**			**EJP**	**ETs**			**VA**
		Elect.	**Heat**	**Fuels**		**Elect.**	**Heat**	**Fuels**	
	Mh	kWh/h	MJ/h	MJ/h	€/h	GWh	GJ	GJ	M€
(n) BCN	10929	0.7	2.4	1.4	5.6	7,139	26,697	15,765	61,527
(n-1) HH	9328	0.3	0.3	0.7	0.0	2,341	2,572	6,626	0
(n-2) RES	9209	0.3	0.3	0.0	0.0	2,341	2,572	0	0
(n-2) MOB	119	0.0	0.0	55.7	0.0	0	0	6,626	0
(n-1) PW	1601	3.0	15.1	5.7	38.4	4,798	24,125	9,138	61,527
(n-2) SG	1410	3.0	2.8	4.6	38.0	4,161	3,990	6,492	53,527
(n-2) PORT	18	10.8	66.7	148.7	81.5	192	1,187	2,647	1,450
(n-2) MC	168	2.3	42.6	0.0	35.4	385	7,176	0	5,954
(n-2) ES	4	14.3	2814.4	0.0	142.3	60	11,772	0	595

Table 3: End-use matrix, including EMDs and EBUP, of the main levels of analysis (n, n-1, n-2) in Barcelona, 2012

	BU	**EMDs**			**EBUP**	**ETs**			**VA**
		Elect.	**Heat**	**Fuels**		**Elect.**	**Heat**	**Fuels**	
	km^2	kWh/m^2	MJ/m^2	MJ/m^2	$€/m^2$	GWh	PJ	PJ	M€
(n) BCN	118.2	60.0	225.8	133.0	521	7,139	26,697	15,765	61,527
(n-1) HH	62.3	37.6	41.3	106.4	0	2,341	2,572	6,626	0
(n-2) RES	51.8	45.2	49.7	0.0	0	2,341	2,572	0	0
(n-2) MOB	10.5	0.0	0.0	629	0	0	0	6,626	0
(n-1) PW	55.9	85.8	431.5	163	1101	4,798	24,125	9,138	61,527
(n-2) SG	37.1	112	107.6	175	1443	4,161	3,990	6,492	53,527
(n-2) PORT	8.3	23.2	143.2	319	175	192	1,187	2,647	1,450
(n-2) MC	10.5	36.6	681.6	0.0	566	385	7,176	0	5,954
(n-2) ES	0.04	1,655	324,656	0.0	16420	60	11,772	0	595

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A closer look at national energy metabolism: multiscale integrated analysis of energy end uses

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Abstract

National economies present unique patterns of energetic performance due to their specific historical path of development shaped by local environmental and specific socio-economic processes in relation with globalisation and international labour division. However, at the same time, their patterns of production and use of energy carriers also share important common features. Understanding the energy metabolism of a country not only involves studying energy production (transformation of primary energy sources into energy carriers) but also energy consumption (transformation of energy carriers into end-uses). The forced relation over these two transformations generates the dynamics underlying the metabolic pattern. We focus here on the consumption side using an innovative method of accounting that combines socioeconomic and biophysical perspectives: Multiscale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). Energy end-uses are characterized: (i) across hierarchical levels of organization of the national economy, including sectors (agriculture, manufacturing and service sector) and subsectors; (ii) according to typologies of energy carriers of different quality (electricity, heat and fuel); (iii) by combining extensive variables (energy and monetary flows/year and labour hours/year) and intensive variables (ratios of energy and monetary flows per hour of labour); and (iv) over the last lustrums. A special focus is here placed on the accounting of human activity (i.e. time use), being a 'sensor' to detect key compartments for exosomatic metabolism and a potential constrain for the upcoming SESs (Socio-Ecological System) transitions. The constrains posed by the human activity budget are here shown via Impredicative Loop Analysis (ILA). The results show that MuSIASEM can effectively describe the metabolic patterns of the different (sub)sectors of the national economy, explain the existing differences in these metabolic patterns (within and between countries), and how these differences do affect the performance of the national economy. We conclude that MuSIASEM is an effective tool to inform debates in the energy policy arena in relation to hot topics such as low-carbon economy, energy efficiency, and the water-energy-food nexus. This study was performed within the broader context of the EU project 'Moving Towards Adaptive Governance in Complexity' (MAGIC).

1. Introduction

Industrial revolution was a turning point in human history due to the impressive changes introduced by moving from hand production methods to mechanical ones. These changes supposed moving from agrarian societies where most of the human activity was manual and dedicated to production of food in a rural context, to industrial and services societies based in the intensification of agriculture and industry where most of the human activity is allocated in services cities consuming material products. The important change in the mode of production is not just a technological issue, but also an institutional one (Marx, 1993). In fact, French or Russian Revolution clearly illustrate how deep are entangled productive forces (means of production and human labor power) and relations of production. Additionally, overall material standards of living have improved (not without inequalities in their distribution) enabling greater life expectancy, lower infant mortality and a reduction of the time and work load.

These important changes were fueled by fossil energy, which since their introduction has not stopped growing. Just in the last decades, world consumption of primary energy greatly increased from 3.8 billion tonnes of oil equivalent in 1965 to 11.1 billion tonnes of oil equivalent in 2007 (BP, 2008). Moreover, all these changes have also led to an unprecedented increase in the planet's population from less than 1 billion people in 1800 to more than 7 billion in 2011, following an exponential trend (the last billion people increased in the last decade). To this regard it is important to be aware that the next energy transition foresees huge technological changes that will not happen in a social vacuum. Nevertheless, the implications of the upcoming energy transition on societal organization seem to be under estimated. In fact, despite considerable efforts in the integrated assessment modeling community to link socioeconomic and resources' dynamics with each other, coupling is weak and simplified at best, and the socio-demographic components rarely interact bi-directionally with the rest of the model.

In that sense, energy transition should be seen as a paradigm shift that "would challenge both the viability and desirability of conventional values, economic structures and social arrangements" (Lieberthal and Lieberthal, 2003). In fact, policy-makers themselves need to become attuned to deep, historically evolving cultural patterns and learn how to engage with meanings that emerge in co-evolution with technological changes. This is an important step towards reflexive discussion about what kind of arrangements are possible in the future, what kind of skills are needed, and how do the materials and know-how connect to the cultural resources people draw on.

A more robust approach to study the metabolic pattern of a modern society is here provided by MUSIASEM (MultiScale Integrated Analysis of Societal and Ecosystem Metabolism) that recognizes that the funds (and their size) allow a functional characterization of the system (Rosen, 1977). In particular, this papers aims at showing the importance of 'hours of human activity' as the "expected" profile of human activity across different compartments of the economy (but also outside) poses a constrain in the '*viable states of admissible environment*' (Rosen, 1977): human activity changes may entail a non linear change in the feasibility of the dynamic equilibrium between: (i) the requirement – what is consumed by the whole economy; and (ii) the supply – what can be supplied by the specialized compartments of society in charge for the production of goods and services. The aim of this paper is twofold: (i) to analyze the impredicative relation between energy and human activity in modern societies and the dynamic equilibrium between supply and requirement of energy via Impredicative Loop Analysis (ILA); (ii) analyze the pattern of HA among different EU countries.

2. Materials & Methods

MuSIASEM builds on the flow-fund model of Georgescu-Roegen as well as on complexity theory. Its theoretical framework has been described in detail elsewhere (Giampietro, 2003; Giampietro et al., 2013, 2012, 2009, 2006, Giampietro and Mayumi, 2000a, 2000b, 1997; Giampietro and Sorman, 2012; Pastore et al., 2000; Ramos-Martin et al., 2007; Sorman and Giampietro, 2011). The flow-fund model proposed by Georgescu-Roegen (1971) provides a solution by making an epistemological distinction between *flows* −quantities disappearing or appearing over a given period of analysis− and *funds* −structural elements of the metabolic system associated with agency (e.g., population, workers, technical capital or power capacity in energetic jargon). The fund elements preserve their identity over the given period of analysis (Farrell and Mayumi, 2009; Giampietro et al., 2012; Velasco-Fernández et al., 2015). Within this model, the sizes of the various flows are determined by the characteristics of the various processes taking place inside society. In turn, these processes are determined by the combination of the size and the metabolic characteristics of the fund elements metabolizing the flows. Flows and fund elements, energy carriers and human

activity in this case, are accounted in each hierarchical level of the system and are here expressed in form of end-use matrix (described in Velasco-Fernández, 2017; Perez Sanchez et al., 2017). The size of the social-ecological system (society) as a whole is defined using the fund element human activity calculated as: number of people × 8.760 (hours of human activity per capita in a year). The size of the different economic sectors and sub-sectors within society is defined as: 'number of paid worked hours per year in the given sector'. The choice of using human activity as scaling factor makes it possible to define the size of the flows of the various compartment in two different ways: (i) using extensive variables – the quantity of flows as resulting from statistics; (ii) using a combination of intensive variables (benchmark values – flow/fund ratio) scaled using the size of the fund element human activity. Knowing the energy flows per hours (the metabolic characteristics of the element) and the hours of work (scaling factor) we can calculate the overall flow.
The first step in MuSIASEM is defining the hierarchical organization of the system: society as a whole is defined as hierarchical level *n* and the corresponding human activity is the THA. This black-box is then divided into two compartments at the lower hierarchical level (*n – 1*): the household sector (HH) and the paid work sector (PW). Correspondingly, the THA is split into human activity in the household sector (HA_{HH}) and human activity in the paid work sector (HA_{PW}). The household sector includes all the activities carried out outside the paid work sector (physiological overhead, leisure, care work, community work, etc.), whereas the paid work sector includes the hours of human activity invested as paid work in the economic process. The pattern of activities can be further refined using additional categories defined at the lower hierarchical level (*n* – 2): (i) agriculture, forestry and fishing AF; (ii) Manufacturing and Construction MC; (iii) Services and Government (private and public services, SG, (iv) Energy and Mining EM; and (v) the household sector (HH, residential consumption including fuels consumed by private cars). The energy supply to society is guaranteed by the Energy and Mining sector (EM) – domestic production – and by imports.
Within this taxonomy we distinguish between sectors expressing: (i) dissipative activities; and (ii) hypercyclic activities. Dissipative activities are those that consume biophysical flows and use exosomatic devices, without producing either of them (HH and SG). In the same society, we must find other activities that generate a net supply of flows and exosomatic funds – in alternative the flows and exosomatic funds consumed have to be imported (the activities generating a net supply of flows and funds are externalized to other societies). The demand generated by dissipative activities defines the required supply of flows and exosomatic funds. The hypercyclic part (= an hypercycle is an autocatalytic loop in which the output is larger than the input) composed by AF, EM and MC has to be able to provide this supply (integrated by imports). The jargon of hypercycle vs dissipative is taken from theoretical ecology (Ulanowicz, 1986), where it is used to describe the factors that stabilize complex metabolic networks in ecosystems. Examples of hypercycle are: (i) the agricultural sector (for food), which produces more vegetal and animal products than it consumes; (ii) the energy sector (for energy), which produces more electricity and fuels than it consumes; and (iii) manufacturing and construction producing more exosomatic funds that they consume. For this reason, the primary and secondary sectors can provide a net flows of food, energy and exosomatic funds to the dissipative compartments of the society.

In order to study the viability domain of a metabolic pattern, MuSIASEM introduces also two concepts: the concept of the dynamic energy budget between hypercycle compartments (Strenght of Exosomatic Hypercycle - SEH) and dissipative compartments (Bio- Economic Pressure – BEP) and the concept of impredicativity. In fact, after having defined the relations between the characteristics of the two sides, that have to be congruent in the dynamic budget, we can discuss future scenarios: for example, we can start setting the characteristics (performance) of the energy sector and then discuss how the society should adapt to this, or, alternatively, we can start designing a (desirable) pattern for the society and then look at the technical characteristics of the energy sector that would be required to achieve the stabilization of this pattern.

The Impredicative Loop Analysis (ILA) is here applied to Spain (ES) in 2012. We used four-angle graphs (Ramos-Martin et al., 2007) to show:

(i) the forced relation among the hours of paid work (HA_{PW}) and the THA in Spain in 2012, and among the consumption of Total Energy Throughput (TET), here calculated as Gross Energy Requirement (GER)[1], per hour basis (TET/hour) and the pace of TET per hour of work in ES (Exosomatic Job Production - ExJP) in Spain in 2012;
(ii) the relation among the hours of the dissipative part (HA_{BEP}) and the THA and among the consumption of Energy Throughput (ET) in BEP, here calculated as Gross Energy Requirement (GER)[1], per hour basis (ET/hour);
(iii) the relation among the hours of the hypercycle part (HA_{SEH}) and the THA and among the consumption of Energy Throughput (ET) in SEH, here calculated as Gross Energy Requirement (GER)[1], per hour basis (ET/hour).

This set of forced relations over a dynamic equilibrium described across hierarchical levels (parts and whole) is at the basis of impredicative loop analysis. We want to show here that this type of representation of the forced congruence over fund elements (i.e. amount of human activity associated with elements defined at different hierarchical levels) and flow elements (specified flows metabolized by the considered fund elements) can be used as a general template for meta-analysis; a template that is very versatile in its possible applications.
In the second part of Section 3, an example of HA analysis, showing the distribution of HA in Paid Work, is presented for 12 EU countries.

3. Results & Discussion

This paper shows part of the results of a broader analysis carried on several EU countries. Table 1 shows an example of end-use matrix for different hierarchical levels in Spain (2012). The end-use array includes extensive variables, in this case HA and ET, and intensive variables, the Energy metabolic rates (EMR_i), that are calculated for each of the energy carriers: electricity, heat and fuel. In MuSIASEM intensive variables provide useful benchmarks describing the qualitative metabolic characteristics of the system's elements (i.e., the inputs required per unit of output). This type of analysis is directly related to the concept of efficiency (production function). Extensive variables, on the other hand, reflect the size of the fund elements (human activity, the agent using and producing flows).

[1]"the total energy is assumed as equivalents of primary energy consumption, i.e. GER – Gross Energy Requirement - (Boustead and Hancock, 1979). In particular 1 J of electricity is here considered equivalent to 2.6 J of thermal energy independently of how and where this electricity is produced (2.6/1 is the average conversion factor observed in fossil-fueled power plants in OECD countries nowdays). This conversion factor assumes that all electricity is produced using one single primary energy source which is fossil energy (Giampietro et al.,2016).

The integrated use of intensive and extensive variable allows us to scale the metabolic characteristics of economic sectors and subsectors within a country, and compare the performance of specific (sub)sectors across different countries. This strategy permits to conserve valuable information about the quality and quantity of energy throughput in the form of different carriers metabolized in each end-use. In this section, we examine the bioeconomic performance of the main economic sectors at the national level: the agricultural sector (AF), the energy sector (EM), the industrial sector (MC), service and government (SG), and the household sector (HH). At this level, we can compare the performance of the various economic sectors within selected national economies, as well as selected economic sectors among various national economies (not shown here). Spain displays an energy sector has the highest metabolic rate of electricity (EMR_{elec}) and heat (EMR_{heat}), and the services sector, as it includes also transport, the highest metabolic rate of fuel (EMR_{fuel}). This is to be expected given that the energy sector is mainly powered by big machinery controlled by few hands (power plants, refineries, liquefaction and regasification plants, etc.), whereas the power capacity in the transport sector mainly consists in fuel converters (cars, motorcycles, trucks, airplanes) that require more human control.
Further details regarding the end-use matrix are available elsewhere (e.g. Velasco-Fernández, 2017).

Table 1: End-use matrix for different hierarchical levels in Spain (2012).
Data sources: Energy Balance Data (Eurostat, 2015a) categorization of Eurostat (nrg_110a); Data on hours worked (human activity − HA) from the *National account employment data* (nama_10_a64_e) (Eurostat, 2015b).

	Spain	HA (10^9h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)
Level N	AS	410	2.2	3.2	3.9	914	1315	1585
Level N-1	HH	380	0.71	0.84	1.3	270	319	480
	PW	30	21	33	36	644	996	1105
Level N-2	AF	1.5	9.9	22	46	14	31	68
	EM	0.18	379	1704	12	68	308	2.2
	MC	5.7	45	99	6.2	256	564	36
	SG	23	13	4.0	43	305	93	1000

A simple example of analysis of the viability of a given metabolic pattern, in this case related to the consumption and supply of energy is illustrated in Figure 1. We consider at the level of the whole society (level *n*) the *fund* element "total human activity" (THA) and the *flow* element "total energy throughput" (TET) which is the total energy (as GER) metabolized by Spain (AS) over the period of one year" by the people living in this society.
THA equals population × 8.760 (hours of human activity per capita in a year). We have also calculated TET (at level *n*) thus resulting in an "Energy Metabolic Rate" - EMR of 9.2 PJ/Mh.

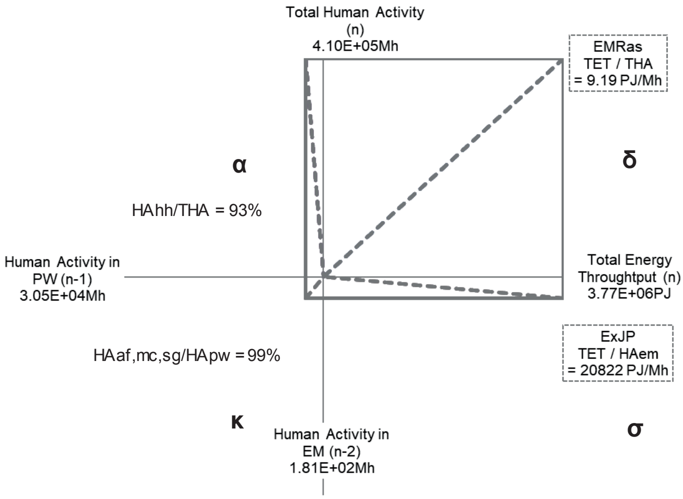

Figure 1: Impredicative Loop analysis (ILA) between HA and ET in Spain (2012).

As illustrated in Figure 1, starting from THA at level *n*, we have to go through a series of overheads to find the size of the EM compartment at level (*n*–*2*) that is in charge for producing energy. The first overhead concerns the share of THA which is not allocated to the paid work sector but to the household sector, HA_{HH}, which accounts for 93% of THA. This overhead accounts for the non-working time of the working population and 100% of the time of the dependent population (children, elderly, unemployed, people who cannot work). Therefore, the share of Human Activity in the household sector depends on factors such as the dependency ratio, the population pyramid, the unemployment rate, etc. The second overhead refers to the share of paid work hours that are allocated to functions other than EM. This second overhead is determined by the ratio HA_{EM}/HA_{PW} and entails that only 1% of the paid work hours are allocated to EM. This corresponds to 181 Mhours of human activity. Thus, the size of HA_{EM} is only about 0.0004 per cent of THA (around 3.8 h/pp/yr)

At this point, one can appreciate the versatility of the set of forced relations. The forced congruence over the lower right quadrant can be interpreted as a *threshold value* which is required to obtain congruence between the requirement of the whole (characterization of society's metabolism in upper right quadrant) and the performance delivered by the EM compartment (the specialized sector in charge for delivering the flow under consideration). Therefore, in theory the EM sector should produce (or import) 3.77E6 PJ of energy with 181 Mhours of paid work in the EM. So, the minimum threshold to achieve congruence is a delivery pace of 20822 MJ per hour of work, as yearly average, in the EM.

The term impredicative loop analysis derives from the existence of *reciprocal constraints*, which are reflected in the four-angle representation (Figure 1):

• In the upper-right quadrant of the figure (metabolism of the whole society at level *n*), we have the angle δ which is proportional to an arbitrarily chosen, desirable characteristic of society. The value of this angle is related to the pace of the metabolized flow under consideration; an attribute of performance for the whole.

- In the upper-left quadrant, we have the angle α which is proportional to the reduction in fund size from level *n* to *n – 1*, that is, the first overhead. In this example, this is the ratio HA_{PW}/THA, defining the share of THA allocated to paid work versus final consumption. This angle depends on demographic variables, but also on social variables and rules (workload, education, unemployment).
- In the lower-left quadrant, we have the angle κ which is proportional to the reduction in fund size from level *n – 1* to level *n – 2*, that is, the second overhead (HA_{EM}/HA_{PW}). The value of this angle is related to the relation between the relative size (measured in hours of work) of the service sector and productive sectors (AF, MC) and the relative size of EM at level *n – 2*.
- In the lower-right quadrant we can represent either an expected value for scenario analysis (expected value) or a technical coefficient (actual value) characterizing a given situation. Thus, the value of the angle σ can be related to either the expected value (the technical coefficient that would be required to get congruence) for the sector under consideration (σ expected), when analyzing the congruence using a top-down approach, or the actual performance of that subsector (σ achieved) when analyzing the congruence using a bottom-up approach.

The same logic can be applied to explain the impredicative relation between BEP and SEH, shown in Figure 2a and Figure 2b. Figure 2a and 2b show that the amount of HA in primary and secondary sectors (SEH) in Spain is very limited, therefore it is quite reasonable to assess that modern societies, like Spain, can maintain their high material standard of living (proved to be linked to BEP) only if they shift the commodities' production (e.g. energy, food, etc) elsewhere.

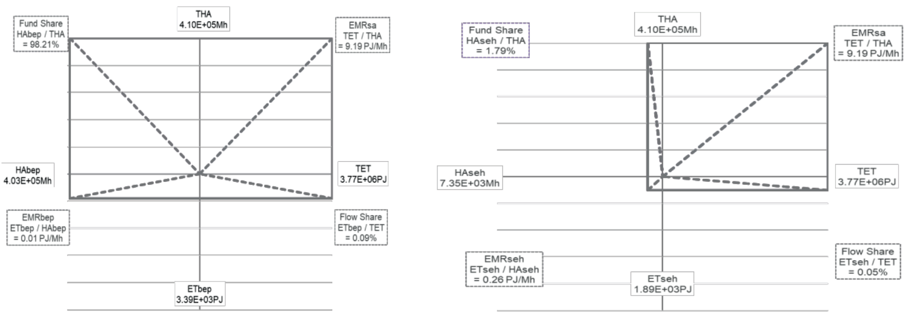

Figure 2: The dynamic budget of HA and ET between BEP, shown on the left (2a), and SEH, shown on the right (2b).

As shown in Figure 3, this metabolic pattern of HA is also redundant in other EU countries where the vast majority of HA_{PW} is allocated to SG, ranging between 400 and 600 hours per person in 2012.

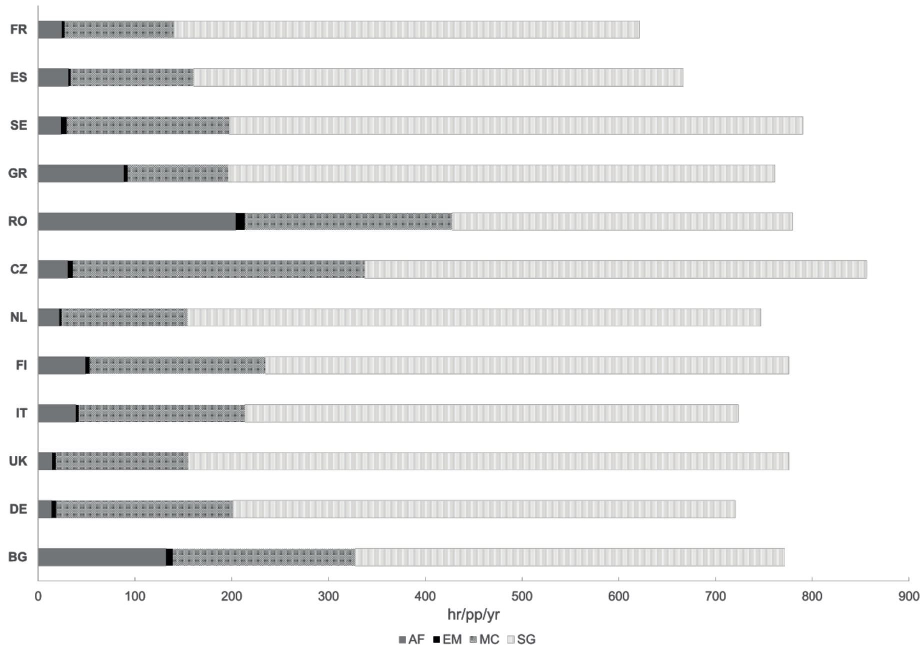

Figure 3: Profile of HA (hr/pp/yr) in PW in EU.

Data source: *National account employment data* (nama_10_a64_e) (Eurostat, 2015b).
List of acronyms: Bulgaria (BG), Czech (CZ), Finland (FI), France (FR), Germania (DE), Greece (EL), Italy (IT), Netherlands (NL), Romania (RO), Spain (ES), Sweden (SE), United Kingdom (UK)

4. Conclusions

Human activity is a factor of paramount importance in quantitative analyses as it acts as a 'sensor' to detect key compartments for exosomatic metabolism and as a constraint on the viability domain of the metabolic pattern of society. The profile of functions (i.e. the difference use of time spent in a society) carried out by the society as whole defines the identity of the system – developed country, rural community, etc. The next socioecological transition (SET), namely moving away from fossil fuels, might have as massive an impact in the long run on the organization of human activity. By using this closed set of reciprocal expected relations over the fund and flow elements, we can perform an impredicative loop analysis to discuss future scenarios.

Acknowledgment

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The full list of references is not included here for lack of space.

Wind turbine aerodynamics analysis

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Abstract

Greenhouse gas emissions, resulting from burning non-renewable energy sources, are recognized as the major cause of global warming. Hence, reducing carbon footprint of energy uses through replacing non-renewable energy sources with renewable ones is believed to be an efficient method for combating climate warming. Wind turbines are one of the most likely initial applications for such sources. A major scientific challenge has thus been the design of a wind turbine performed efficiently to boost their power out-put and reliability as well as the socio-economic effects of low-carbon technology.

This paper presents a study that realized the performance characteristics of Horizontal Axis Wind Turbine (HAWT) from an aerodynamics perspective - by focusing on analyses of aerodynamic forces acts on the rotor - analytically using Blade Element Momentum (BEM) as well as numerically with the use of the commercial multi-purpose Computational Fluid Dynamic (CFD) solvers ANSYS 13.0 - FLUENT and CFX. For this study, the Tjaereborg wind turbine with blade's airfoil of NACA 4412 (National Advisory Committee for Aeronautics, NACA) was selected. The lift and drag coefficients are computed for different angles of attack using (BEM) theory with fixed pitch angle. Moreover, flow around the airfoil simulated; contours of static pressure and velocity as well as velocity streamlines show that there was no noticeable boundary layer separation experienced on airfoil surfaces. Finally, a simplistic analysis is carried out for the turbine rotor in order to evaluate the impact of transition to turbulence and flow field distribution on turbine performance. Results were analyzed to estimate the power output from the turbine.

1. Introduction

The use of renewable energy technologies addresses three contemporary concerns simultaneously, i.e., economic growth and positive impact on livelihoods; local environmental protection; and the saving of global CO_2 emissions which would otherwise be released if fossil fuel sources were used instead. As to the local environment, while the addition of modern energy can facilitate development, it may, however, also have negative impacts or drain scarce financial resources, both of which could be mitigated if technology solutions were selected more carefully. Wind turbines in particular are able to generate enough electricity to increase people's welfare by improving living conditions and protecting the natural surroundings and global atmosphere.

The designing of a commercially viable wind turbine, that needed to make the wind power economically feasible, is oven require the maximization of the efficiency of converting wind energy into mechanical energy. Among different aspects involved, rotor aerodynamics has been selected as a key to achieve this goal. Although the significant progress in the 30-year history of modern wind energy, which has improved the efficiency of the primary process from 0.4 to nearly 0.5 (Carlo, 2008), many phenomena e. g. atmospheric boundary layer flow - mainly in the inboard - causing stall-delay effects are still not fully understood. Concerning the unsolved problem, mainly engineering methods have been proposed. Most of these techniques are not universally applicable, so that a better physical understanding is needed.

Studies on wind turbine aerodynamics have been given in the literature with the focus on three approaches to analyze the flow around and downstream of a wind turbine. They are summarized as follows:

i. On the subject of wind tunnel testing, (Hiroshi, 2000) mentioned the wake visualization of Horizontal Axis Wind Turbine (HAWT). This has been examined, in National Renewable Energy Laboratory (NREL).

ii. (Gordon, 2011), (Pramod, 2011), (Martin, 2008), (Ingram, 2005), (Manwell, 2002) and (Burton, 2001) provided extensive surveys of the literature on the analytical and semi-empirical models. They focused their attention on the classic momentum theory, Blade Element Momentum (BEM) theory, and Blade Element (BE) theory combined with vortex wake models.

iii. (Versteeg, 1995) began to explore dynamic capability of CFD. Also, (Ferziger, 1999), (Jorge, 2001) and (Jiyuan, 2008) pointed out the descriptions of fundamental CFD theories, basic techniques, and practical guidelines. In addition, a similar approach was taken by (Carlo, 2008) consider in the blade inboard and tip design, the boundary layer and the near wake flow. His simulation performed using FLUENT as a solution package.

The main objective of the current study is to provide a better understanding of the physical behavior of the flow field past wind turbine rotor. Moreover, it is also aimed in general to study the capabilities of modern numerical techniques applied in the complex fluid dynamic problems.

2. Materials and Methods

2.1. Analytical study:

The performance of a HAWT can be predicted analytically using the BEM theory that equates two methods of examining how a wind turbine operates. The first method is to use a momentum balance on a rotating annular stream tube passing through a turbine. The second is to examine the forces generated by the airfoil lift and drag coefficients at various sections along the blade (blade element). The combination of these two methods give a series of equations that can be solved iteratively (Ingram, 2005). The BEM theory basically assumes that the blade can be analyzed as a number of independent elements in a span wise direction. The equations of the BEM theory given by (Martin, 2008) and these equations used to analyze the performance of a blade of Tjaereborg wind turbine, which has specifications that taken from (Database on Wind Characteristics, Tjaereborg Wind Turbine Data: 1991-1992) and shown in Table 1.

Table 2.1: Specification of Tjaereborg wind turbine

Number of blades	3
Blades profile	NACA 4412
Rotor radius	41.5 m
Nominal rotational	22.36 rpm
Annual mean wind	8 m/s
Cut-in Wind speed	5 m/s
Cut-out Wind speed	14 m/s
Hub height	61 m

2.2. Numerical study:

The commercial tools, ANSYS FLUENT 13.0 and ANSYS CFX 13.0 have been used to investigate Two Dimensions airfoil analysis (2D) and Three Dimensions blade analysis (3D) respectively. These packages are finite volume-based solver, which allows both structured and unstructured grids to discretize the computational domain. The ANSYS codes generally consist of three large parts that are corresponding to three phases of the problem analysis denoted as: (1) Pre-processor, (2) Solver and (3) Post-processor (ANSYS, 2010). The computational domains for both 2D airfoil analysis and 3D blade analysis are shown in Figures 1 and 2, respectively.

During the creation of the mesh around the airfoil, great care must be taken in the vicinity close to the airfoil surface in order to take into account the effect of the boundary layer that might be formed.

In order to perform a 3D blade analysis, the refinement of the mesh in specific regions of the model can be accomplished with the use of *Mesh Controls*. In the present study, *Mesh Inflation* control is applied to the blade and hub surfaces.

All rotor computations were performed at constant uniform wind speeds, pitch and rotational speed. Thus, a 120 degree periodicity was applied, and only one blade was modeled in order to save the computational resources.

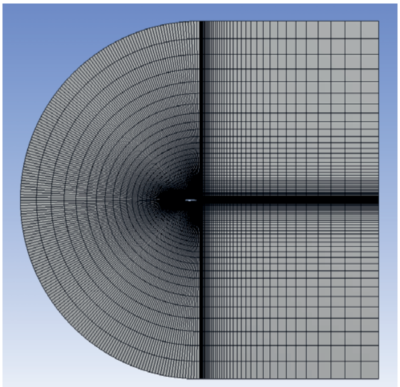

Fig. 1: Mesh generated for the airfoil section

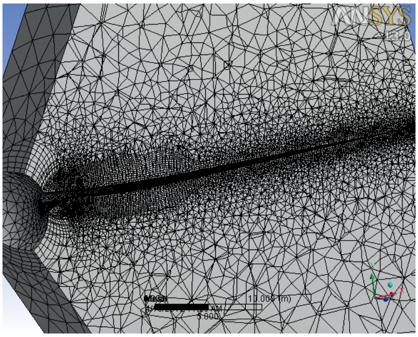

Fig. 2: Concentrated mesh generated around blade and hub surfaces

3. Results and Discussion

3.1. BEM Code Results

The code splits the blades into ten elements and applies the BEM theory algorithm specified in section 2.1, to determine the maximum power coefficient C_p over a range of specified Angle Of Attack (AOA) increments. This has been done at (AOA) ranging from 0° to 12° and the velocity of 8 m/s. The outputs of the code plots in curves of the power and thrust coefficients versus angle of attack (AOA) over the specified angle of attack range are shown in Figure 3.

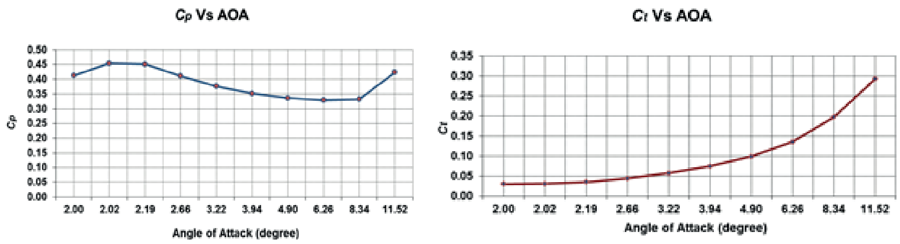

Fig. 3: Power coefficient (C_p) (left) and Thrust coefficient (C_t) versus angle of attack (AOA)

Figure 3 illustrates that the blade with angles of attack 2.02° and 11.52° provides a maximum power coefficient (C_p) of approximately 0.45. Thrust coefficients (C_t) do not exceed 0.05 up to angle of attack ~ 3°. Beyond this attached angle, i.e. from ~ 3° onward, the thrust coefficients have been increased gradually, i.e. approximately 0.29 at maximum angle of attack 11.52°. These may reveals that the designed angle of attack is 2.02° - could provide maximum C_p, i.e. 0.45 and minimum C_t, i.e. 0.05. Thus, this designed angle of attack has been chosen for further analysis - in particular, in the 2D airfoil analysis described in sections 3.2 and 3.3.

Mathematical representation of the correct lift and drag coefficient values and correct evaluation of the axial and tangential induction factors was difficult because there are different Reynolds number (Re) for each section along the blade (due to the variation of cord *c*). For current analysis a constant Reynolds number, i.e. 5.51*10^5 calculated along with constant cord - assumed to 1 m.

3.2. Airfoil Analysis Results

The velocity contour, pressure distribution and velocity streamlines at a designed angle of attack are shown in Figures 4 and 5 respectively.

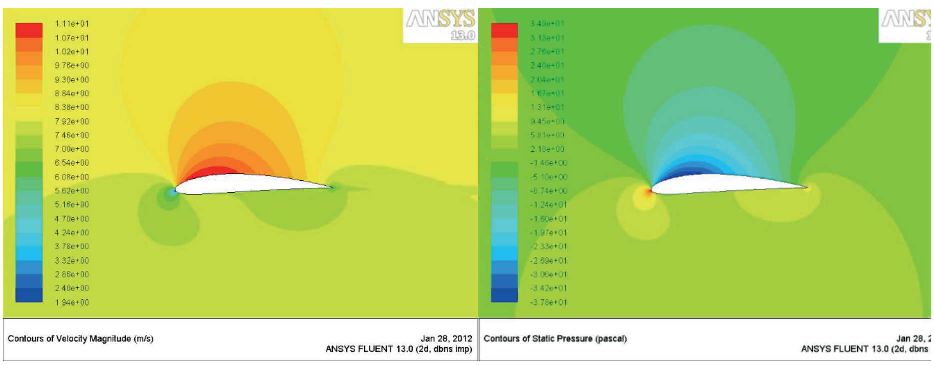

Fig. 4: Contours of velocity (left) and static pressure at designed angles of attack

The results presented in Figures 4 and 5 illustrate that the pressure on the lower surface (pressure surface) of the airfoil was greater than that of the incoming flow stream and as a result of that it effectively pushes the airfoil upward, normal to the incoming flow stream. On the other hand, the components of the pressure distribution parallel to the incoming flow stream tend to slow the velocity of the incoming flow relative to the airfoil, as do the viscous stresses. It could be observed that there was no noticeable boundary layer separation experienced on airfoil surfaces due to the small angle of attack.

The lift and drag coefficients calculated from ANSYS FLUENT software were $C_l \approx 0.74$ and $C_d \approx 0.006$, which - obviously - close to those found out from BEM analysis - in section 3.1 - ($C_l \approx 0.77$ and $C_d \approx 0.01$). These results may verify the accuracy of the BEM analysis.

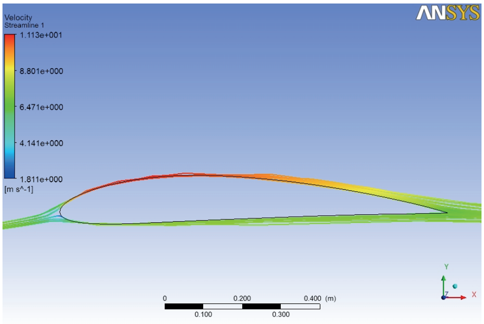

Fig. 5: Velocity streamlines at designed angles of attack

3.3. Blade Analysis Results

The results of one blade analysis have been integrated into all three blade (full rotor simulation) by create three copies of the domain and transfer it by 360 degree around the Z-axis. Figure 6 present the surface velocity streamlines, and the 3-blade rotor colored by variable pressure forces.

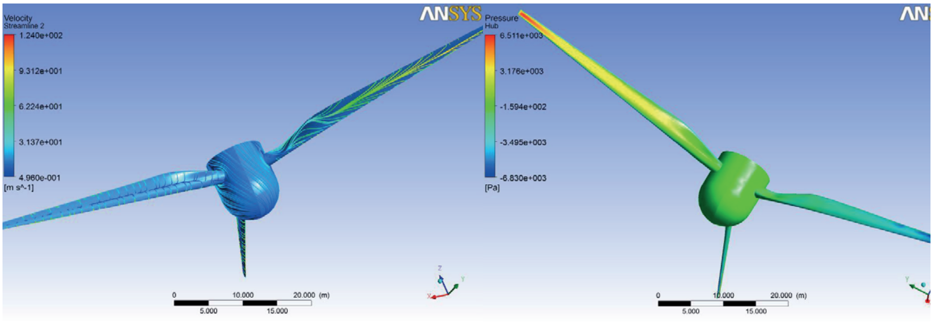

Fig. 6: The surface velocity streamlines (left) and 3-blade rotor colored by variable pressure forces

The previous figure exhibits the produced surface velocity streamlines, which prove that the flow was fully drifted. Also, it highlights the blade area that should be carefully considered in the designing of blade structure.

Results from the 3D analysis have been used to estimate the torque and power output from the turbine. They reveal that the power output is at the level of 790 kW.

The results obtained have also revealed an agreement of below 500 kW with the corresponding ones given in the literature (Figure 7), i.e. the result presented in the Tjaereborg wind turbine database. However, the power estimated by the CFD code was output from the rotor while the figure illustrates the actual electrical power output (produced) from the turbine.

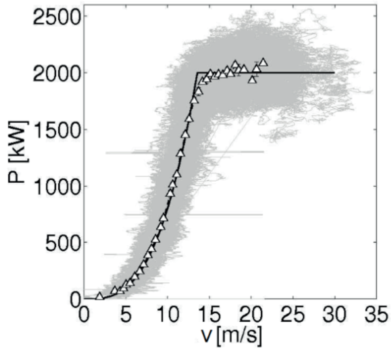

Fig. 7: Power curve for Tjaereborg wind turbine

4. Conclusion

The main goal of this paper is carrying out a better understand of the aerodynamic behaviors of the blade and rotor of wind turbines. For this, a 3-blade horizontal axis wind turbine with NACA 4412 airfoil analyzed. The results were quite satisfactory. They can represent a good foundation for future work in this area.

The primary value of the BEM theory at a fundamental level is that it allows for a good understanding of the effects of varying geometrical and aerodynamic parameters on the overall performance characteristics of a HAWT. More importantly, the BEM can be used to predict the necessary pitch setting of a pitch regulated wind turbine. A pitch regulated wind turbine may operate at a fixed pitch until a certain nominal power is generated. For higher wind speeds the blades are pitched normally with the leading edge into the wind in order to keep this nominal power.

The results from this work support the potential of CFD use in the commercial wind industry for the evaluation of blade performance. At this stage, the investigations involving the application of a fully turbulent Shear Stress Transition (SST) model were at an early stage, and more work needs to be done in order to establish the most favorable setups for obtaining optimal results. In order to increase the accuracy of the simulations, several of the investigations already initiated in this work should be continued.

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Usability of in-home energy displays and energy saving: a design case

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Abstract

Buildings play a big role in energy consumption rates at global levels, and the reduction of their impact on greenhouse gas emissions as well as their increased efficiency represent a global challenge. Many researches demonstrate that, despite relevant advances in buildings sustainability field on technical side, energy consumption rates remain still high and this is due to occupants' behaviour. Direct feedbacks on real time energy consumption give the most specific, reliable and credible information and gain people's attention more than any other kind of information, allowing 5%-15% energy saving rates. Therefore, among the strategies to induce environmental friendly behaviour in buildings occupants, smart metering is gaining room, and usability of in-home energy displays is acknowledged as the most relevant factor for the effective comprehension of monetary and environmental effects of energy related behaviours. This paper presents the guidelines for the user centred design and experimental installation of a smart metering system in a social house block in UK. A set of directions about interface usability, examples for optimal installation and service organization are provided, taking into account social and personal characteristics of intended users and basing on the analysis of the context of use. The smart metering system delivered uses a wall-mounted tablet aimed at displaying real-time information and control functions for main powered home devices in flats mainly hosting low-income and/or elderly peoples. At earliest stages of the study, specific characteristics of users, tasks, tools and environment have been surveyed. Afterward, guidelines about textual information, and namely about: type and style for fonts, fonts size, colours and background/foreground contrast, language and wording, increasing user focus have been elicited, together with guidelines for screen layout and information architecture (that is menu levels) and for tablet positioning in the intended environments.

1. Introduction

It is widely acknowledged that buildings are one of the main sources of energy consumption, corresponding to 20- 40% of global energy consumption (Perez-Lombarda et al., 2008). Despite many investments on green and smart buildings and on appliances efficiency, it is known that buildings with similar technical characteristics (same occupants number, same property, some income levels, etc.) present wide differences in energy consumption, confirming the relevance of users' behavior in energy demand (Duca, 2014).

Furthermore, it is demonstrated that green buildings can produce GHG emissions up to three times the expected levels and this is due to occupants' behaviors that, if are not addressed to correct behaviors, may dramatically increase the planned emissions' targets (Bourgeois et al., 2002). Feedbacks to steer positive users attitude and behaviors towards energy is a much more cost-effective strategy compared to investments on buildings (Gardner and Stern, 2002), with the advantage of changing behavior patterns, and gaining immediate results with minimal required infrastructures. Today this strategy is based on smart meters; these instruments are able to record energy consumption in real time providing relevant metrics to both building occupants (that can set energy aware behaviors), and energy service providers, that become able to optimize their technical infrastructure and business offer. Smart meters allow a greater accuracy in energy accounting and billing, a deeper understanding of financial and environmental effects of powered appliances and devices use habits, the possibility to remotely control powered devices according pre-determined consumption or price thresholds. Even if recent experiments demonstrate the usefulness of smart metering (Ayers et al., 2009), critical aspects for such devices are emerging, linked to poor usability of systems displaying energy information to energy users. In fact, several experiments demonstrate that users engagement, with their consequent environmental friendly behavior, decreases in long term in field tests (Davis, 2011); furthermore the effectiveness of monetary benefits such as rewards or billing cuts seems to be rather uncertain in wide experimental panels (Houde et al, 2013).

2. Smart metering and users

Recent qualitative studies on the installation of energy feedback devices confirm that their usability is a key factor to ensure the effectiveness of smart metering and can bring to 15%-25% reduction of energy consumption rates (Chiang et al., 2014; Pefferet al. 2013). A further user variable of smart metering is the link among income, education level and mean for energy information display: it is known that SMS or digital displays in buildings common areas have a reduced impact on occupants' behavior, whilst the same feedbacks are much more impacting if they are provided throughout smart TVs or personal displays, especially for high income families (Dahlquist et al., 2013). Therefore, it is very important to deliver energy information profiled for specific users groups, with a specific attention to digital divide and low income population, as usability of smart metering systems increases the effectiveness of decision making about energy consumption and allow the achievement of expected savings (Hauge et al, 2011; Wilson and Dowlatabadi, 2007). Occupants can cut up to 10%of energy consumption immediately after receiving real time feedback (Gardner and Stern, 2002). Indirect energy feedbacks as information displayed in billing (Darby, 2006; Kerrigan et al., 2011) give only an overall and weak view of global consumption and need to be elaborated before they reach intended target (Darby, 2006; Kerrigan et al., 2011), whilst direct feedbacks from smart meters give more accurate, reliable and credible information, highlighting real time energy savings and catching people's attention more than any other information mean about energy consumption, achieving 5%-15% in final energy saves (Darby, 2006; Oltra et al., 2013). Most recent developments in energy feedback technologies encourage the use of in-home energy displays providing highly profiled information for specific user (Fischer, 2008; Jimison et al., 1997; Fogg, 2003). Thus, in order to achieve the biggest benefit from such a technology it is necessary to ensure a good interface design, as energy saving rates depend on the engagement of the whole population at large (Wood and Newborough, 2003; Duca, 2016).

3. Guidelines for usability of in-home energy displays in social housing buildings

3.1 The context of use of in-home energy displays

Within the presented case study, in-home energy displays have been installed in 200 flats of a social-housing block in Exeter (UK). The smart metering system foreseen by the project is based on a wall-mounted tablet to display real time data on energy consumption and to control home appliances in elderly and/or low income families. In order to ensure that system features match the specific characteristics of intended users, a typical software usability approach has been followed (ISO, 1998). Therefore, the context of use of the in-home energy display that could affect participants' behavior and data comprehension has been analyzed, detailing specific characteristics of users, tasks, equipment and environment.

Target users for the experiment include elderly and poorly technology educated people; often elderly people fall into the technology poorly educated people group. Elderly (over 60) characteristics to be taken into account in the purpose of the experiment are: reduced visual acuity, higher probability of color blindness and general reduction of color recognition ability, alteration of colors perception (like a slightly yellow film covering the view), reduced tolerance to glares and to lighting discomfort, reduced reading speed, reduced ability for fine movements (low accuracy), slower movements, reduced extent of joints movements and reduced reachability area (Ziefle and Bay, 2005; Akutsu et al., 1991; Omori,et al., 2002; Dillon, 2004). It has to be considered that those characteristics start to appear in 40 aged people and may have wide subjective variations . For what concerns technology poorly educated people, personal characteristics to be taken into account are: low trust in the system (that means eventually: reduced self-confidence in information comprehension and uncertainty about undertaking an "energy related" action on appliances); fear to make interaction mistakes and fear to not be able to recover (that means eventually the risk of avoiding interface navigation); unfamiliarity with technology symbols and language; unfamiliarity with basic input/feedback mechanisms.

Tasks requested to the smart meters users are: understanding displayed information; undertaking an action on an appliance/system and browsing the interface to get more energy info details or to send commands to any appliance. Those tasks are not key tasks in participants' everyday life, and therefore their successful accomplishment relies mainly on their personal motivation and engagement in the experiment (as it can be supposed that the amount of monetary reward is interesting for participants but is not sufficient itself for keeping them in a long term engagement). For that reason, display design and installation should allow users to grasp displayed information even with unintentional looks at the displays, providing easy to use data and tips. Furthermore, under the participants' point of view, time can be a not relevant variable for energy related task, since they are free to prioritize energy related tasks and their everyday tasks according personal preferences/needs. Anyway, about this point it should be considered that a timely perception of energy information and a consequent timely execution of energy related tasks might impact energy consumption rates and, eventually, participants' motivation and overall success of the experiment. Hence, as far as possible, interface should be able to catch users' attention at a given moment while they are involved in other tasks. Always for priority/engagement reasons, browsing energy information and remote control of appliances should be as easy and quick as possible, preferring wide horizontal rather than deep navigation paths.

Another type of users' data to be taken into account are anthropometric measures for an comfortable visual an tactile interaction. For what concerns view angle, reference measures are given by the green angle in Figure 1, to be used with anthropometric tables, so that we can roughly consider the minimum height for human eye at 1410mm (female 5 percentile) and maximum at 1760mm (male 95 percentile).

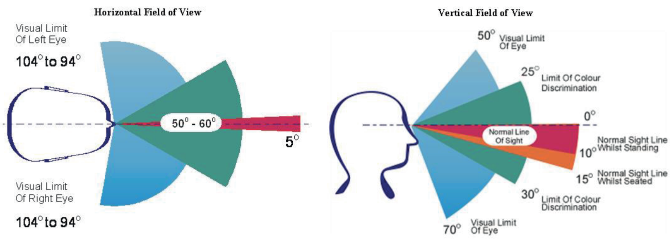

Figure 1: Angle of comfortable view

Anthropometric data should also be used to assure a comfortable tablet reach for both hands. If (as presumably) physical interaction happen from a standing position, it should be considered that tablet distances from the body should allow tapping and dragging keeping the hand not higher than the shoulder; also a complete extension of the arm should be avoided. In worst cases, reaching the tablet must not require to rise the elbow over the shoulder height. For distances, we can refer to the reference measures in Table 1. Finally clearance for feet and legs should also be checked before installation, to assure a safe/comfortable approach to the tablet.

Table 1 Main body measures

Body position	short	average	tall
Standing stature (cm)	150.5 (cm)	167.5	185.5
Forward grip reach (cm)	65.0	74.3	83.3
Eye height (cm)	140.5	156.8	174.5
Shoulder height (cm)	121.5	136.8	153.5
Sitting height (cm)	79.5	88.0	96.5
Sitting eye height (cm)	68.5	76.5	84.5
Sitting elbow height (cm)	18.5	24.0	29.5
Body weight (Kg)	44.1	68.5	93.7

For what concerns the environment, tablets are installed in living environments, which can vary very much according buildings' features and households' preferences, and this may produce some constraints for the tablets installation. The main environmental aspect to take into account is lighting, which might produce glares and finally make reading uncomfortable or impossible; therefore, before each installation, possible problems due to natural or artificial light sources in the room should be checked (Ziefle, 2005).

3.2 In-home energy display usability guidelines

Basing on the above described context of use, a set of guidelines has been defined to deliver an usable in-home display interface and a smooth handover of the whole smart metering system to engage users for the whole experiment.

For what concerns fonts type and style, following specification have been drafted (Slattery and Rayner, 2013): use sans serif font; do not use more than one font type;

in case of space constraints choose a font with a high gap between the body and ascenders/descenders lines (x-height) or use light fonts (some similar to ITC Officina Sans Book and Calibri light) as they are more readable and can be used at a smaller dimension, keeping good readability; do not use more than two font dimensions, the biggest for titles or main contents (to be grasped at a glance) and the smallest for more detailed/secondary information, with two dimensions well differentiated; do not use capitals, italic, bold, underlined (use underlined only for web page links, if any). Font size depends on reading distance, Table 2 and Table 3 provide guidance to find best font size for normal visual abilities (Ogilvy, 1983). Moreover it is suggested to start sentences, fields name and any piece of text with a capital letter (e.g. “Won’t you use the hob instead of the kettle?”, “Today so far” etc.).

Table 2: Font sizes to be used when creating a poster (Source D. Ogilvy)

Item	Font Size (points)	Comments
Title	150+	You want your title to be visible from across a room!
Headings	48	Should be easily readable for anyone walking nearby.
Subheadings	36	This text should be readable from at least 5 feet away.
Main Body Text	32	This is a comfortable text size for someone reading from a distance of 5 feet (7.5 m).
Captions	24 – 32	It's OK to make these a bit smaller than the body text if necessary.

Table 3: Font sizes and reading distances (Source D. Ogilvy)

Reading Distance		Minimum Comfortable Font Size	Comments
1.2 feet	0.35 m	8 points	This is the typical reading distance for a book. Most people prefer text to be 10, 11, or 12 points at this distance.
2.4 feet	0.7 m	16 points	This is the closest comfortable distance for reading a large poster.
5.0 feet	1.5 m	32 points	In many settings this is as close as one can get to a poster. Sometimes this is because the poster is roped off, or in other cases, large crowds simply make close approach difficult.
25.0 feet	7.5 m	160 points	For almost any setting, you want a title that can be read from at least this far away.

In case of screens placed out of the optimal view field, fonts dimension should be slightly increased and, in case screens must be read by elderly, reference measures should be slightly increased, too. When increasing font size, it must be considered that too big fonts result in poor readability, therefore in case of uncertainty it is better to select the smaller alternative (Legge and Bigelow, 2011). On the other hand, too small font size might result in unread/misunderstood data because of poor texts readability and reduced users engagement, due to the fact that users must intentionally decide to read displayed data rising their sight from a closer distance to access information. A further feature of the in-home energy display are colors and background/foreground contrast; it is suggested to assure the highest possible contrast. Best contrast is given by yellow background with violet text or yellow background with black text. Nevertheless, for design aesthetic or further reasons, other color pairs can be used. In that case, it is advisable to check the contrast with one of the many available tools[1], or just making a screen capture and turning it in balck and white. Moreover a plain background must be used, not overlaying text on images and not relying on colors for conveying information (e.g. green/red for an ok/not ok status must be accompanied by a well contrasted text or symbol) (Dillon, 2004).

Language and wording must be clear and precise as far as possible and users must be allowed to associate the information they are looking at to a specific equipment/behavior/room. Vocabulary must always be simple and polite, avoiding exclamation marks, emphasis and humor; acronyms and measurement units should be avoided unless they are very common in everyday life. When prompting an action, the sentence should be written stating the goal that you mean is achieved and then, if applicable, how/why it can be achieved (e.g. “To get this, do that”). Sentences length should be kept in one line, additional lines (in a smaller font size) can be used to provide secondary information or to provide a title/key for information fields (ISO, 2006).

To increase users focus (Arnheim, 1974), following guidelines can be addressed: display the main monitored data in the top left area of the screen (if a hierarchy exists or if it is tested within the experiment scopes); make recognizable what is new and/or updated in the last 60/30 minutes and the most relevant information at the moment (e.g. presenting data/prompts in a reverse background-foreground style for the first 5/10 minutes). Any text that should prompt any user action could be displayed as a slowly sliding sentence at the bottom of the screen (like breaking news stripe in TV); also for these texts, if updates are occurring, a reverse background-foreground display for 5/10 minutes would be suggested as well as any other suitable change in interface attracting users’ attention.

Since many participants might be not familiar with touch screen technology, deep navigation paths with many tapping or dragging tasks should be avoided. Also information overload and crowding should be avoided to assure its maximum readability and comprehensibility. Therefore, the in-home energy display interface should present all information that users are expected to deal with in the main screen page, allowing the access to detailed information or advanced functions with only one further navigation level. Functions or information accessed by hold gesture should be avoided (this must be avoided especially if a tap command is associated to the same interface object); they must be arranged in a clear and plain layout, based on few main visual axis and focuses. Adequate spacing between information blocks and between text lines should be assured; data and functions must be grouped according the everyday life experience and grouping logic should be clear for people not used to technology. A button for quick return to the main page from any other page must be provided, together with clear (and possibly textual) feedback to any user action. This is very relevant in case of appliances control from the in-home energy display interface.

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[1] I.e.: http://snook.ca/technical/colour_contrast/colour.html

In order to avoid installation errors that might affect whole smart metering system effectiveness, attention must be paid in physical installation of the displays. For instance, tablets could be installed on a swivel/mobile arm, so that their position can be set according users' personal preferences. This will allow to adjust reading and touch distances, meeting a sufficiently wide range of abilities and also optimal rotation for glares avoidance. In addition, after handover/training phases, it can be useful to leave users a paper leaflet with a quick guide and a full description of the interface; also performing an usability trial of the in-home energy display and its directions leaflet with a pilot group of householders before installation might help to maximize the impact of the smart metering system (5 persons would be the best, but fewer will be anyway helpful). User cold be offered a touch pen to make tapping tasks easier (elderly might prefer), and trained to adjust screen brightness to their preferences. Finally, a contact point available for the whole trial period would increase confidence in the system, pushing people to use all provided functionalities.

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Energy and Wellbeing in Latin America: Political and Cultural issues

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Abstract

The concept of wellbeing varies along time and geography. In Europe, nowadays, it means living in the city with comfort, with few concerns about economic difficulties, social classes' struggles and climate change menace. Probably, the main worry is how to preserve the benefits obtained through five centuries of exploitation of conquered territories. This philosophical attitude is supported by a science unable to integrate social, economic and ecological perspectives. A critical analysis could show the enormous flow of richness that allowed the European high standard of living, other ways impossible to attain. In Europe, scholars discuss wellbeing and degrowth, ecological socialism, epistemological decolonization and rescue of the cooperative modalities of production and consumption. Besides that, a critical analysis is needed to inform about the real sustainability of technological innovations on course.

In Latin America, there is a wellbeing model known in Quechua language as "Sumakawsay" ("Living with plenitude"), that breaks-up capitalism postulates. In some regions, this ecological and democratic culture based on indigenous traditional knowledge remains alive supporting sustainable societies despite the continuous aggression by governments and corporations. It promotes the use of local resources and low use of external inputs (in other words: autonomy and sustainability). It is a commoners' life-style in the countryside with equitable trade that is able to support a relatively high density of people in rural areas and support, up to a certain point, urban consumption. In times of dramatic global crisis, "Sumakawsay" can be a reference in the transition to sustainable societies in Europe and Latin America.

How these two different models can establish a dialogue? First, it is necessary the critical diagnosis of current system that is leading us to a collapse and species extinction, including human species. Second, as global change demands concerted actions all over the world, it needs an international holistic scientific effort with intensive communication. Third, it is necessary to discover who is doing what, how, when and where in relation with Ecological Wellbeing or Prosperous Way Down that involves ecological growth and degrowth of fossil energy economy. Fourth, it is necessary to create interaction spaces for those who are working on solutions for present time's dilemma. Fifth, Odums´ modelling and simulation tools should be used to make evident the trends we have ahead us. To illustrate these predicaments, it will be described a case-study using emergy methodology.

The Context (the current global crisis)

Capitalism requires continuous growth and achieves this through the conquest and colonization of territories to extract their wealth and generate monetary accumulations, which create sharp differences between poor and rich people. In the last five decades, neoliberal policy imposed austerity on governments which drastically reduced social care. Thus, for most Latin Americans, neoliberalism is a nightmare due to falling incomes, rising unemployment and the withdrawal of public services as health, education, security and social welfare (Barkin, 2001).

Under these circumstances, in Latin America a significant number of people seek to build their own forms of survival, many of them precarious and incapable to provide minimum income needed. Other people are forced to emigrate and accept heavy and temporary jobs, which deteriorate their life quality and disintegrate their culture. Thousands of people, among millions who live under precariousness, begin to think about alternative strategies, some of which arise from examples of indigenous communities (Barkin, 2001, Martínez Alier, 1995).

As consequence and considering the environmental crisis, evidenced by the Climate Change, it is necessary to study the traditional model of production and consumption of indigenous populations, which can be used as a basis for a high ecological and social sustainability model. However, to create a model for population masses, it's necessary to develop **politic strategies** within a social system of high complexity and variability.

According to Barkin and Lemus (2015), the sustainable development strategy should be based on five principles: (a) autonomy, (b) solidarity, (c) self-sufficiency, (d) productive diversification, and (e) sustainable management of local resources. All of this, with participation of local community in planning, implementation or maintenance of a sustainable economic and social processes, and in obtaining a surplus to support community activities (Barkin, 2001).

On the same perspective, Acosta (2016) points-out: (a) the stopping of population growth; (b) the reduction on oil and mining dependence, (c) the elimination of monoculture, (d) the waste reduction, (e) the wealth and income redistribution, (f) the change of technological standards, (g) the creation of a common sustainable culture all over the world. This would slow down the entropy increase and would strengthen the neguentropy.

It is already known that the rich countries pattern of consumption cannot be generalized or maintained. Besides that, the natural resources (water, air, soil, forests, oceans, biodiversity) and the vital ecosystem functions they generate to regulate biogeochemical cycles and absorb the waste generated by the current civilization are at risk. There is great concern about the deterioration of the biosphere consequences (Wilson, 1992).

While economic progress enriches a few and stimulates the growth of "modern" sectors, it does not meet the needs of the majority. For this reason, the search for sustainability requires a strategy to overcome the modern dualism (dominant elites and excluded people), and thus, while seeking autonomous solutions, the marginalized sectors must be strengthened.

In some Latin American countries, such as Ecuador and Bolivia and, on a smaller scale, Peru and Mexico, this is possible by their historical process, their ethnic composition and culture (Barkin, 2001). For example, the rights of nature and indigenous nations were incorporated into the constitutions of Ecuador (2008) and Bolivia (2012), as subjects of law that require full restoration in case of degradation. In other Latin American countries, the transition is more difficult because of the Eurocentric Culture dominance.

The pre-text (a reflection about the crisis causes and possible solutions)

Creating true sustainable development requires a new culture, therefore a new social pact, taking as base an ecological diversified production and distribution structure designed to eradicate poverty and to include the excluded and among them the nature. It would be a culture capable of recreate life (Barkin, 2001).

Barkin and Elizalde (2012) wonder what can be drawn from the various future projections and how to generate the social power needed to react. They and other scientists, as Dussel (1990, 1995); Odum and Odum (2001); Hinkelammert and Mora (2005), consider that the basic challenge is to subordinate Economics to Ecology and Ethics.

The current problems cannot be solved by the philosophical and pragmatic principles that led to Capitalism. In this sense, in Europe there are criticisms about the economic progress indicator (Gross Domestic Product - GDP) (Stiglitz et al., 2009) and about the idea of unlimited continuous growth and the need of Degrowth (Latouche, 2009). Besides that, most of "Green Economy" large-scale technological proposals are very questionable. They have a fragmented vision of the global system and of its impact on biogeochemical cycles and on excluded communities.

To escape the neoliberal fallacy, post-capitalist and pre-capitalist utopias are needed, including the indigenous peoples sustainable worldviews, nowadays increasingly strong. The premise is to adopt a social-ecocentric vision, rather than the anthropocentric, incorporated in both capitalism and socialism (Acosta, 2016). It is time for sustainable development, but that demands **confrontation** of the rich minority interests that defines our way of life. Acosta (2016) says that "Well-living" or "Sumakawsay" is a proposal that questions the Eurocentric well-being concept and that faces colonialism and domination in all its forms.

It is necessary to deconstruct both the growth economy and the consumption society, regarding that **decline** itself does not guarantee a social or ecological improvement if it is not accompanied by other changes. It does not consist only in exploitation opposing or in **working time reduction** in the light of technological progress; it requires a radical transformation in the production and consumption patterns. We must think of a **self-determination culture to empower communities** to confront and regulate the economic system (Acosta, 2016).

There are fundamental ethical questions regarding the global structure perpetuation that generates inequality, a reality that must be overcome. Facing the crisis of an urbanized and overpopulated global society requires a critical and urgent reflection (Barkin, 2001). For this objective, it is essential to start with a **common future vision** for the whole society, to reverse the historical tendency of enriching the few with the detriment of the majority (Barkin & Lemus, 2015).

The text (principles and strategies to overcome the problems)

The first issue to be addressed is **self-sufficiency** in relation to market economy integration. The global trade promotes specialization based on monoculture systems. In contrast, the ecological solution recovers the biodiversity in human organization. Historically, rural communities are characterized by **diversity in productive activities** for subsistence and require local administrators to manage complex natural systems. Sustainable development strategies must recover and preserve the traditional knowledge and assume that productive diversification must be linked to the basic social needs and local available resources (Barkin, 2001).

To achieve sustainability is required **direct participation** of beneficiaries and also of those potentially affected; there is a consensus that participation must go beyond consultation and must integrate people into real power structures. This implies in a **redistribution of political and economic power**.

Alongside **political mobilization**, people must **understand the dynamics of natural and political processes** to reorient human systems to preserve the planet's ability to support present generation and host future generations (Barkin, 2001). A valuable discovery is people´s ability to "**recreate solidarity with each other**, when the state does not interfere" to solve common problems and to initiate creative processes for social benefit (Ostrom, 1993).

On the other hand, we must find out why the state is unable to **strengthen the oppressed**. In ultimate analysis, sustainable development implies a political struggle to control the apparatus of production, processing, marketing, consumption and recycling, and the allocation of surpluses.

As it has been said, in many regions with indigenous populations, the wisdom is transferred through generations. Current research on ethnobotany, ethnobiology, agroecology, and agroforestry is systematizing this wisdom, but the benefits could be transferred to large corporations instead of the communities.

Ecological Economics research show that the traditional systems productive potential is greater than the conventional agriculture, but there are cultural and political factors that prevent their full deployment, including the disrespect for indigenous culture. The findings are transferred as fragments rather than as wholes to the "modern" farming systems that do not desire to change their world vision (Barkin, 2001).

It is not a question of "reinventing" the peasant economy, but carving out political spaces to allow them to exercise autonomy and guide their organizations and production, first for themselves and secondly for trading to the rest of society. The opportunities for new forms of social organization based on natural resources are great and those initiatives to implement such projects gradually meet many interested people in the cities (Barkin, 1992). In the case of policies for species conservation, a promising proposal is the creation of "peasant's biosphere reserves" and "land restoration groups", where local communities are encouraged to continue living in their region, through an agreement which accepts that local community preserves the space and enjoys a sustainable quality of life with full political participation.

Sustainable development is not consistent with the expansion of so-called "modern" commercial agriculture, because this production based on the use of agrochemicals and machinery that increases the primary products production by using petroleum-based industrial inputs, but has high social and environmental costs. This type of rural development has led to the marginalization of peasants and indigenous people (Acosta, 2016). The peculiarities and importance of **traditional production systems** must be recognized to overcome the exclusion of their products, since now they are commercialized only within informal markets.

Both capitalism and socialism have established dual or bipolar economies that create great differences between the social strata, especially on capitalism. Those differences must be recognized, as first step, to support governments and society to design policies aimed at promoting the general well-being.

In short, **a broad global pact to strength the social base** is needed to make possible the transition towards true sustainability. A **common strategy** should orient the organization of a net of **supporting structures** to provide training in Systems Ecology, Political Theory, Ethics and Philosophy of Liberation and Communality to motivated people aiming to empower social movements all over the world. These critical topics will be discussed in future papers.

Study cases

The current model and the proposed model for true sustainability model

Using systems language (Odum, 1994, 1996) it is possible to show how it works the current global economy (Fig.1) and how could be organized in the future (Fig. 2).

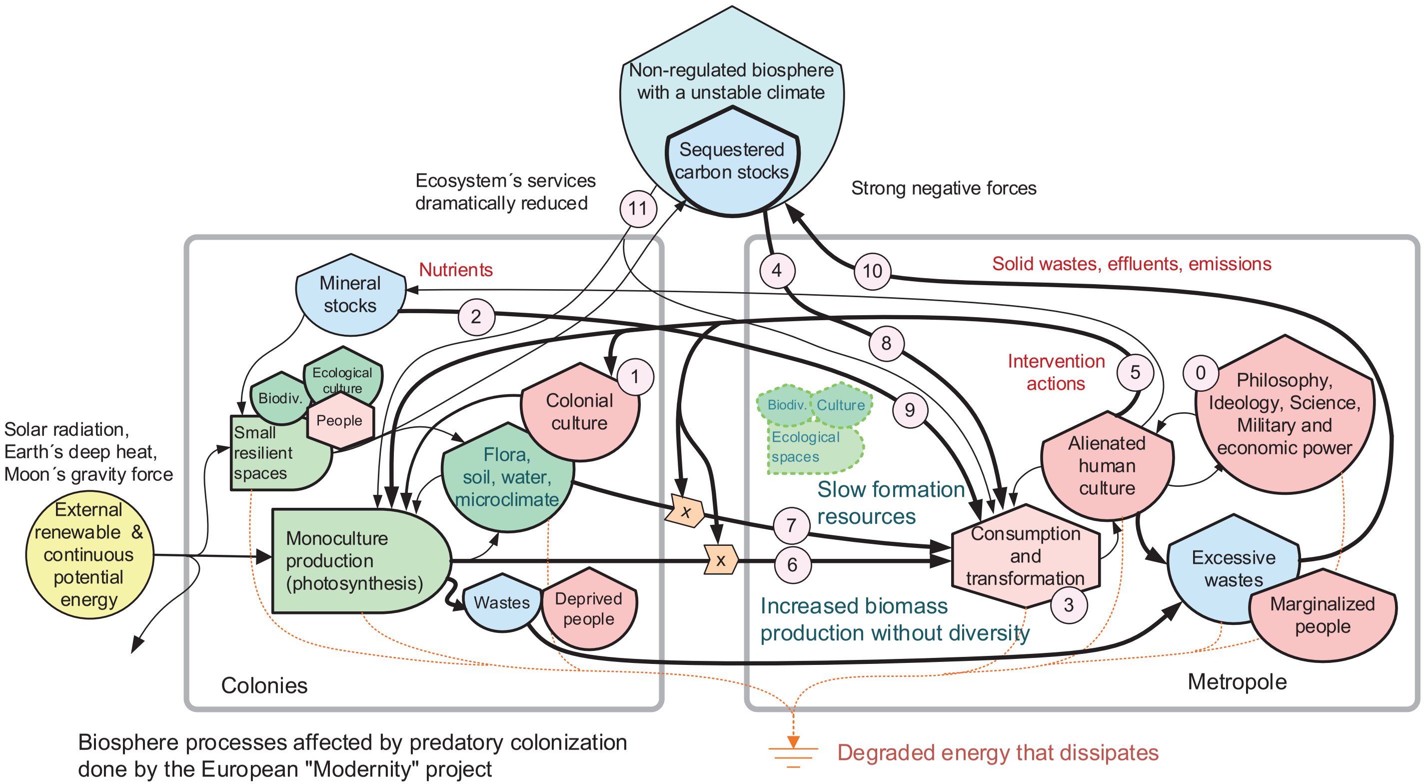

Figure 1. Diagram of energy, material e global economy flows from global economy, showing stages during expansion of capitalism.

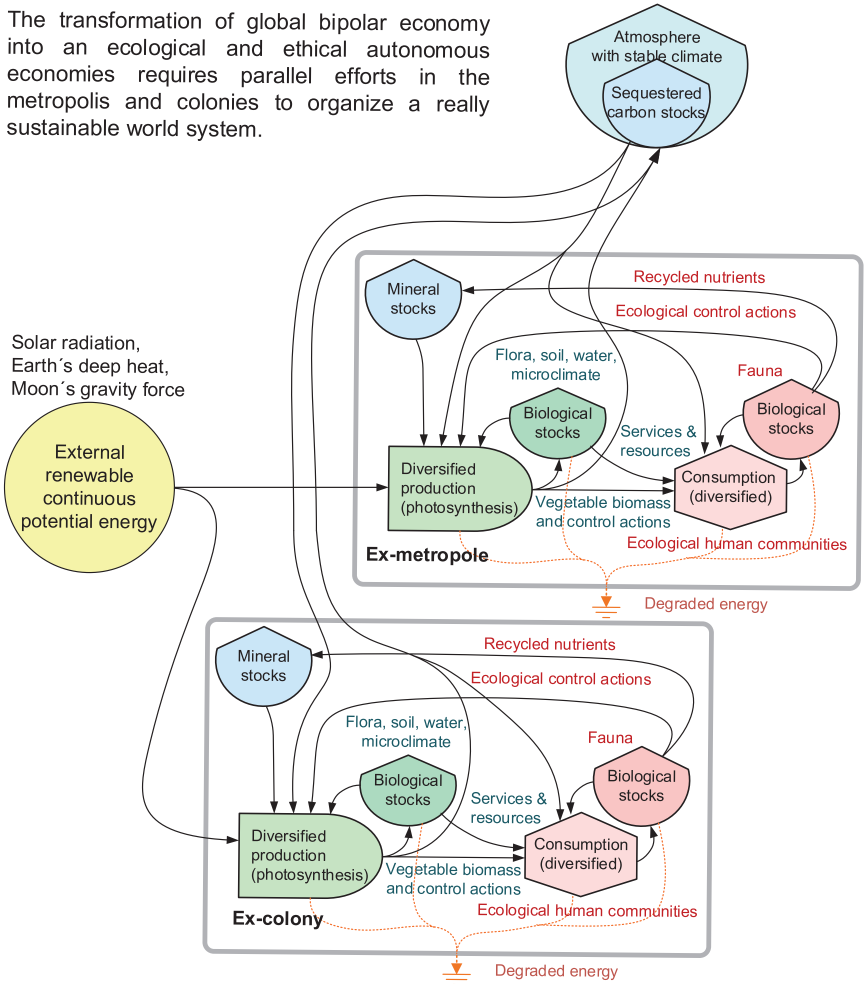

Figure 2. Biosphere processes in equilibrium, after the end of anthropic domination, in a new kind of economy devoted to human and ecosystems wel-being

The example of ecological transition in a rural property

The *Aparecida do Camanducaia* Farm, in São Paulo, Brazil, underwent a radical change in the last ten years due to the information received from an ecological rural community. Bellow, emergy and social indicators are shown. Productivity increase and incorporation of trade allowed recovering of profit and quality of life.

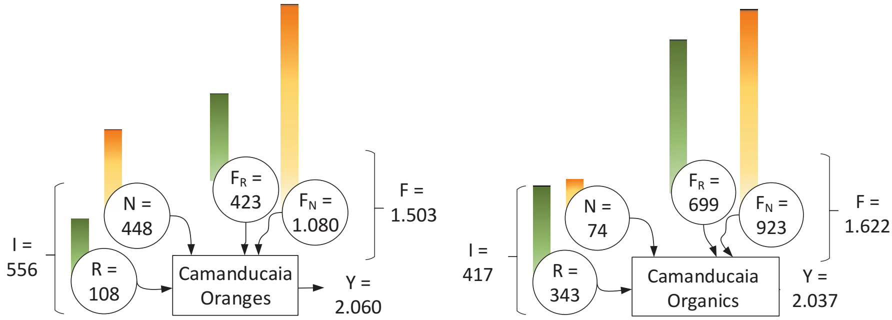

Figure 3. Emergy flows comparison of Camanducaia Farm when it was an orange monoculture and when it became an organic horticulture. The diagrams present four inflows and one outflow. Resources from nature: R=renewable and N=non-renewable. Contributions from Economy: F_R=renewables and F_N=non-renewables. Y= Emergy in products energy (E) (See Ortega *et al.*, 2002).

Table 1. Thermodynamic and social Indicators from Camanducaia Farm

Description	Formula	Chemical Oranges	Organic vegetables
Transformity (the inverse of ecosystem´s efficiency)	Y/E	2 988 272	179 126
Renewability (Renewable resources fraction)	$(R+F_R)/Y$	25%	73%
Emergy Yield Ratio (Emergy from environment)	(R/F)+1	1.07	1.21
Emergy Investment Ratio (Economy/Nature)	F/R	13.92	4.73
Emergy Exchange Ratio (Richness transference)	Y/em$	1.66	0.56
Environmental Loading Ratio (Non-renew./Renew.)	$(N+F_N)/(R+F_R)$	2.93	0.36
Population Density (People/hectare)	Workers/Area	0.21	0.90

The simulation of a global ecological transition considering public policies

We adapted a model that simulates a metropole control on a colony (Odum & Odum (2000), to run on Matlab[1], aiming to use artificial neural networks techniques. So far, the response of parameters (biosphere resources and flows) over time is satisfactory.

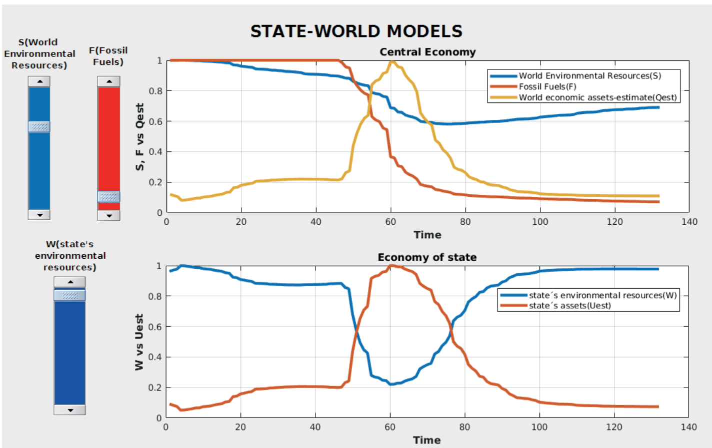

Figure 4. Representation of the behavior of the metropolis and the colony over time

[1] Matlab-Mathworks. https://www.mathworks.com/products/matlab.html

As it can be seen in Fig. 4, at time 60 (parameterized) the global system reaches its climax and begins to decline, ideally towards an ecologically and socially balanced system. In the model tested until now, does not include the social forces.

In the study of the transition of current global system to an ecological autonomous economy, it will be necessary to incorporate the forces that participate in the social and biological regeneration as parameters that represent public policies. The inflection point and the decline curve are determined by the interaction of social forces. Therefore, there is the intention of testing the software with many people interested on the global process to obtain a really sustainable global system.

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Smart Energy Systems and the Plans for Renewable Energy. Perspectives for more Integrated National and European Planning

Henrik Lund

This lecture presents the learning of a series of studies that analyze the problems and perspectives of converting the present energy system into a 100 percent renewable energy system using a smart energy systems approach. As opposed to, for instance, the smart grid concept, which takes a sole focus on the electricity sector, smart energy systems include the entire energy system in its approach to identifying suitable energy infrastructure designs and operation strategies including transportation and aviation. The typical smart grid sole focus on the electricity sector often leads to the definition of transmission lines, flexible electricity demands and electricity storage as the primary means to deal with the integration of fluctuating renewable sources. However, the nature of wind power and similar sources has the consequence that these measures are neither very effective nor cost-efficient. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating sector and/or the transportation sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems. This presentation illustrates why electricity smart grids should be seen as part of overall smart energy systems and with the case of Denmark illustrate how to design such future energy system.

Beyond growth: Economics as if the planet mattered

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Abstract

To borrow a phrase from the title of E.F. Schumaker's book Small is Beautiful: economics as if peopled mattered, we take a slightly wider perspective, suggest an economics as if the planet mattered and pose the question… Can the planet accept more BUSINESS AS USUAL? In an earlier paper (Brown and Ulgiati, 2011) we framed the economic system as a subsystem of the larger more encompassing geobiosphere and suggested that within this context, neoclassical economics is unlikely to provide sufficient explanation of the 2008 economic meltdown. From this biophysical perspective, we suggested that increasing the amount or speed of money circulation as well as extracting more energy from whatever sources may be available will only compound the problems in the long run and that relying on growth as the solution to what ails the global economy is not a desirable nor a tenable solution. Finally, we concluded in that paper the problem is not just resource availability, or getting the "growth engine going again". The real problem is BUSINESS AS USUAL. At the 2012 BIWAES, we explored the implications of the continuing "financialization" of the world economy and suggested that it threatens the security of nations as it precipitates boom and bust cycles and fosters resource imperialism (Brown and Ulgiati, 2015).

In this paper, we look back at the last 9 ½ years and suggest that all the tweaking with capitalism that has gone on is only rearranging the deck chairs on the "titanic" so to speak. And therefore, we recognize that what is needed is an alternative economics. We need a new economics, that is not based on unlimited growth... that does not assume the agents acting within it are rational... an economics that does not create artificial markets where there are none, an economics that does not equated money with wealth, but instead recognizes that true wealth is resources...an economics that actually measures well-being instead of GDP,..an economics that treats nature as the source of all wealth instead of an externality.... an economics that redefines money....an economics that demotes finance to its proper role as a tool rather than a source of profit...an economics that is based on longevity and quality instead of quantity and throughput. What ever term we finally use to describe it, above all it must be, as Buckminster Fuller said, "....an economy that works for 100% of humanity."

1. Introduction

Following the 2008 global economic crises we worried that the current economic paradigm (neoclassical economics), fixated as it is on growth, will result in a "growth at any cost" mentality which could easily translate into increasing world tensions and ultimately even larger global economic crises (Brown and Ulgiati, 2011). Later, in the proceedings of the 8th Biennial International Workshop on Advances in Energy Studies we explored the implications of the continuing "financialization" of the world economy and suggested that it threatens the security of nations as it precipitates boom and bust cycles and fosters resource (not just energy) imperialism (Brown and Ulgiati, 2015). Now looking back and projecting forward we wonder if it is possible to change course and develop an economics as if the planet matters. We wonder if growth now generates more costs than benefits and is thus uneconomic. We question the inevitability of globalization and economic growth as the answer to global poverty.

2. Economic Growth: the decoupling of resources and money

Since the world economic crisis of 2008, the world economy, as measured by GDP, has "grown" at an average annual rate of 2.3%. Much of that growth was captured by China and India (8.4% and 7.1%, respectively) while the USA grew by an annual average of 1.3% (Figure 1). While it is well known that GDP has increasingly been challenged as an appropriate measure of the productivity of economies, with numerous alternatives proposed [1] to account for losses of natural capital, ecosystem services and other negative effects, it is still used in national accounts and by the vast majority of economists and financial advisors.

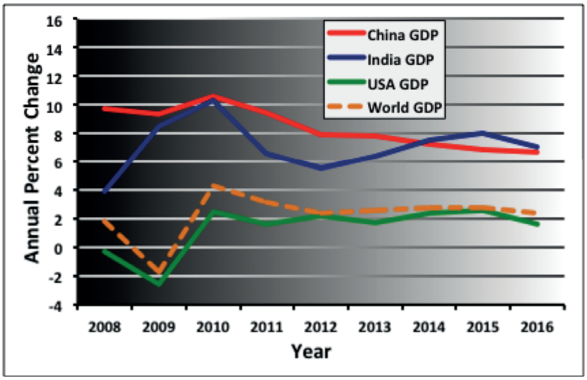

Figure 1. Annual GDP growth of China, India, the USA and world average, 2008-2016

Daly has critiqued GDP as an index of wellbeing and suggested: "GDP is not a measure of wellbeing or even of income. Rather it is a measure of overall economic activity... defined as the annual market value of final goods and services purchased in a nation, plus all exports net of imports."

In our 2011 article (Brown and Ulgiati, 2011) we evaluated the economies of the USA and India in 2010 and showed that the financial sector of the USA actually was responsible for over 50% of the GDP and that of India was 35%. Daly (2011) suggested that the financial sector comprises 40% of total world profit. What this suggests is that growth in the GDP is captured mostly by the financial sector in developed economies and exhibiting impressive growth rates in developing economies...which represents a rather lopsided and relatively inaccurate view of the "improvements" that increases in GDP are supposed to bring to well-being. In fact, the opposite is true. As Daly (2011) and others have been saying for many years, growth in GDP alone

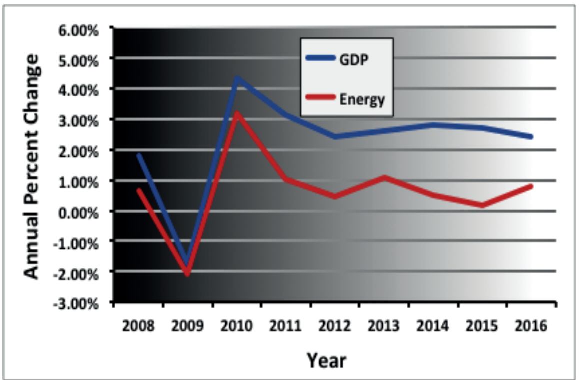

Figure 2. Annual percent increase in Global GDP and energy throughput, 2008 – 2016.

[1] For an excellent review of indicators see Wuppertal Institute, 2010.

does not account for loss of natural capital, degradation of the environment, and decreases in societal welfare, but instead treats these "negatives" as positives, adding them to GDP.

Counting GDP as the main indicator of wellbeing decouples the monetary economy from the environment, natural resource base, resource throughput, and social wellbeing. The sole purpose of economic policy, under the GDP illusion, becomes increasing GDP, rather than societal welfare since the neoclassical belief is that GDP ultimately measures wellbeing. Nothing could be farther from the truth. Figure 2 provides proof of the decoupling, showing the annual percent increase in global GDP (World Bank, 2017), and energy use (British Petroleum, 2017). The overall average annual percent increase in GDP was 2.3% while for energy throughput was 0.6%. In other words, the percent change in market value of final goods and services purchased on the global market was considerably higher than the energy throughput. The difference between these two growth rates represents the degree to which the monetary economy is decoupled from its biophysical basis.

Our critique in 2011 (Brown and Ulgiati, 2011) proposed, that decoupling of GDP (i.e., monetary flows and subsequently economic policy) from energetic realities was tantamount to inviting catastrophic economic failure as more and more of the economy was only illusionary, composed of stocks, collateralized debt obligations, derivatives and other "exotic instruments" that have little to do with the performance of the real economy.

As further proof of the decoupling of GDP from any semblance of societal welfare, Figure 3 shows the global average per capita GDP and per capita energy throughput. Global per capita GDP has increased an average annual rate of 1.2% since 2008, while the annual increase of per capita energy throughput has *decreased* 0.5%. The difference between these two rates of growth highlights the degree to which they are decoupled. Many economists and energy analysts insist that this difference is indicative of increased efficiency in the economy as energy intensity (unit of energy through-put per unit of GDP) is decreasing. However, from a biophysical perspective it suggests an uncoupling. By this we mean that since resource throughput is the real measure of economic production, the fact that GDP increases faster than resources means that "market value" of final goods and services purchased is increasing faster than the underlying basis for the production of those goods and services. Unless goods and

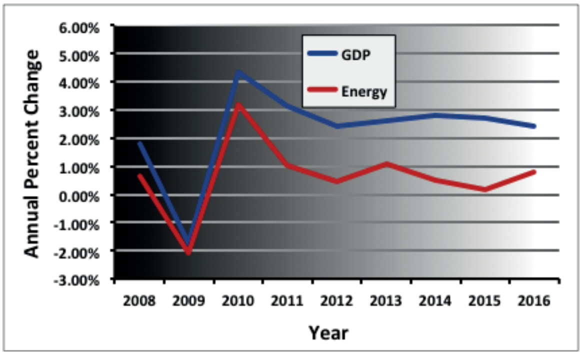

Figure 3. Global per capita GDP and per capita energy through-put 2008-2015

services can be made to appear without an expenditure of energy and input of other natural resources, more money per unit of output is not the result of increased efficiency, but of an inflated monetary measure of economy. [2]

3. Understanding costs and constraints

It is well known and widely accepted worldwide that monetary costs are not a sufficient assessment of the investments and the impacts of a process or an economy. There is no need to spend too many words to point out that market driven monetary costs - while unavoidable and not to be disregarded - are too dependent on contingent events, political strategies, alliances, and also short-sighted plans. Figure 4 shows the historical trend of oil prices from the year 1973 to date. Since the 1973 oil crisis and throughout the following years of strategic management of oil resources, oil prices have been used as a way to affect international policies and interfere with decision making, alliances, and internal and international stability. Very seldom, if ever, oil prices have been dictated by real scarcity, perspectives on energy futures, self-reliance strategies of national economies, different environmental and thermodynamic quality of resources, or even environmental concerns. Every important change in the graph in Figure 4 can be associated with international political turmoil more than to increased understanding of the ability of oil to sustainably drive the future of our planet. Similar considerations can be made for other fossil fuels, for nuclear energy (where the military option and national status play a huge role), for minerals (consider the internationals arguments about "rare earths", especially between China and the USA), for water and - last but not least – for land. Monetary costs reflect the desire of an economic actor (a nation, a corporation, an individual entrepreneur, or an individual citizen) to acquire a resource and support an economic process (either production or consumption). Seldom, if ever, do other unintended consequences that may result from the process affect the cost.

"Cost" is not only monetary cost. The concept of cost expands to encompass all kinds of upstream and downstream impacts that are associated with a resource entering a production or consumption process. The most common alternative concept of "cost" refers to the energy cost, i.e. the number of joules is takes to make a resource available or to process and deliver a good to a potential user. Markets and political strategies may change the monetary cost of a resource but they can do little to affect the amount of energy that is needed to acquire, process, and convert a kg of mineral or metal resource into a manufactured product. While improving technologies may slightly lower the energy costs, there is no escaping the 2nd law. The impossibility

Figure 4. Historical trend of oil prices (www.tradingeconomics.com)

[2] It is possible that decreases in the energy intensity of an economy can result from increasing efficiency of conversion of resources into finished goods and services, and certainly this is the case in some instances, yet it cannot explain all of the difference between resource throughput and GDP. If it did, then inflation would be zero instead of averaging around 2-3% annually.

of escaping the energy and material constraints is slowly spreading and becoming a shared understanding.

Upstream and downstream impacts affect wellbeing of our societies:

- By “upstream impacts” we refer to the depletion associated with withdrawal and use of resources including things like: water depletion, fossil fuels depletion, soil erosion & land cover change, as well as the depletion of stocks that used to be renewable - such as fishery and forests stocks - that are no longer renewable due to excess rates of extraction). Depletion is a different "cost" aspect, in the broader sense that refers to a situation in which a resource becomes no longer available, similar to situations in which increases in monetary costs makes something no longer reachable by a number of potential users.

- By “downstream impacts” we refer to airborne, waterborne and solid emissions that lower the quality of life of a population, due to alterations of biosphere dynamics. Such impacts, most known as environmental impact categories in Life Cycle Assessment, span from global warming potential, eutrophication potential, ecotoxicity and human toxicity potential, acidification, among others, and clearly represent new bills to be paid by societies in order to support economies and lifestyles.

Last but not least, resources are generated by the biosphere dynamics at different speeds and in different amounts. The biosphere, powered by the main driving forces of solar radiation, deep heat and gravitational potential, provides ecosystem services and cumulative ecosystem storages, generally referred to as natural capital. The services and capital of the biosphere can be quantified by means of the Emergy Accounting approach (Odum and Odum, 2000) thus providing a biosphere-based footprint that goes beyond monetary-based value, by providing what is really missing in economic accounting…Nature (Figure 5). It is useful here to recall the quote "*Ecosystems of the world are threatened because market prices are used to evaluate them*." by H.T. Odum and E.P. Odum (2000).

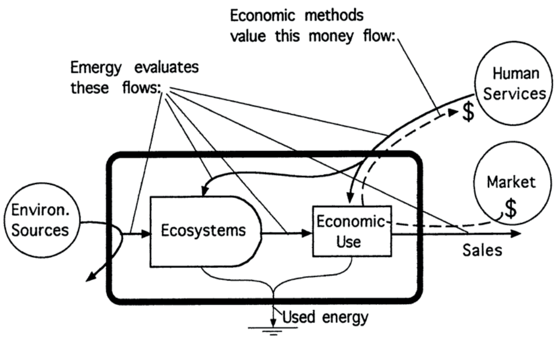

Figure 5. Interface between ecosystems and economics

4. Indicators of Declining Wellbeing

Since the ninth BIWAES meeting, there have been significant world events, that are changing the global system and that require our attention. Cheap oil has once again caused many to forget the peak oil reality and suggest that growth is still the future. We are in a perpetual “war against terrorism” with expenditures of resources and the loss of lives that is not sustainable and appalling in its devastation. It appears that many countries are turning inward, closing borders and worrying about protecting themselves from imagined terrors and unfair trade. We learned just a few days ago that a trillion ton, 6000 km^2 piece of ice has broken off Antarctica… possibly the result of global climate change… and yet leaders of the United States have pulled the country out of the 2015 Paris Climate Accord saying that climate change is not real. Since our last workshop, we added 140 million people to the world population and pumped 76 billion tons of CO_2 into the world's atmosphere. Estimates of the number of species that have gone extinct in the two years since our last conference are between 17,400 and 110,000 (the unfortunate thing …we really don't know how many). In these past two years about 14 million hectares of new deserts have been created and 150 billion tons of soil has been eroded. Since our last workshop, we have lost 21 million hectares of tropical rainforest and another 5 million hectares of temperate and dry forests to various forms of "development". The world has gotten a little warmer, a little more dangerous, a little more crowded, and a bit less diverse[3].

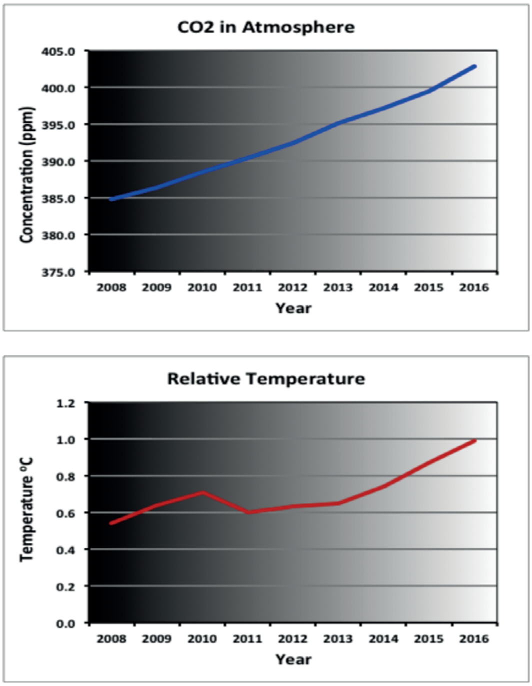

Figure 6. Relative temperature and atmospheric CO_2 levels; 2008-2015.

The recent increase in human suffering, as millions of people are torn from their homelands, either because of war or environmental change (Figure 7) is another indicator that something is wrong. War is profitable, for those who produce arms and their manufacture and sale add to the global GDP. But the human suffering, the loss of human productivity and the impact on nations accepting refugees are not factored in.

These indicators need be factored into our measures of progress. The GDP does not reflect these costs, if it did, quite frankly, the world would be experiencing at best no growth, and probably more realistic, negative growth. There is information enough from the world's scientific community regarding the over exploitation of the biosphere to suggest that continued growth in GDP or resource throughput is not sustainable, Yet, all the rhetoric we hear from policy makers, and their "economic advisors" is that growth is the answer to everything. World poverty? Grow the economy and trickle down will take care of it. Income inequality? Economic growth is the answer.

[3] The authors wish to thank David Orr (1994) for his inspiration in crafting this paragraph.

Inadequate nutrition? Grow more food. Environmental pollution? We can grow our way out of it.

5. Wealth: A holistic view

Wealth is considered by most as an accumulation of money. A wealthy person is a person with lots of money, a wealthy community is often thought of as one that has a lot of wealthy people (meaning lots of money). Yet, when we consider a wealthy state, or a wealthy nation, a different concept of wealth emerges and energy, material and environmental resources enter the picture. A nation that is wealthy is a nation that has an abundance of resources.

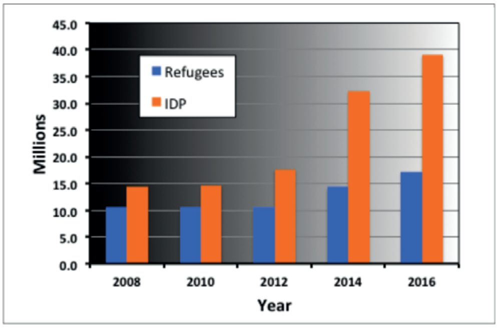

Figure 7. The increase in refugees and internally displaced persons (IDP), 2008-2016

The wealth of a nation is the nation's resource base. This has been well recognized throughout history. Prior to the current preoccupation with money, economists considered a more physical basis for wealth. Smith, in *The Wealth of Nations*, described wealth as "the annual produce of the land and labour of the society". Before him, the physiocrats, lead by François Quesnay, believed that the wealth of nations was derived solely from the value of land. Following Smith, Ricardo and Marx were convinced that wealth stemmed from labour. An obvious consequence of these viewpoints should be that the wealth of a nation is it's natural, human and physical *assets,* or *capital.* Natural assets include such things as land, forests, fossil fuels and mineral resources. Human assets include the education and/or skill levels of the population, while physical assets include the manufactured capital (roads, buildings, machines, etc.).

In the last 50-100 years, the popular usage of the term "wealth" has defaulted to "the state of controlling or possessing items of economic value usually in the form of money, real estate and personal property". The shift has resulted from the general concepts of monetary economics, which provides the framework for money as medium of exchange, store of value and the unit of accounting.

Unfortunately, the today's preoccupation with money has translated into measuring the wealth of nations as the monetary value of that which is produced. Viewed in this way, the wealth of nations is the market value of final goods and services produced within a country in a given period of time, known as the Gross Domestic Product (GDP). Contrary to how most view the economy, however, the monetary value of that which is produced is not a real measure of wealth, but instead is a measure of what people are willing to pay for wealth. In other words, the natural, human and physical capital and the products generated from that capital are the true wealth, and market price (monetary value) is only a way of valuing it from a human perspective.

6. A New Economics

To say current economic theory emphasizes growth is an understatement. The entire system is based on growth. Yet unbridled growth in a finite world is not only impossible, but also meaningless. It ignores the physical and thermodynamic realities and suggests that limits imposed by space, or resource availability do not apply to the affairs of humans. Neoclassical economics denies any dependence on nature or natural resources. Some economists suggest that nature and resources are not scarce while others suggest that scarcity doesn't matter because it is possible to substitute labor, capital or manmade artifacts for natural resources. In either case, neoclassical views of nature and resources are that there are no limits. To keep within the energy field, the assumption that present fossil energy use can be fully replaced by renewables so that nothing else needs to be changed in our economies, not only disregards the huge constraints placed by minerals, but also ignores the different power density between renewables and fossil sources.

Based on resource constraints and increasing world population, we propose a new economics that requires a much deeper understanding of the relationship between humans and natural systems, an economics that views humanity and nature systems as a coupled system, an economics that recognizes that the source of all wealth is natural capital (the sum of capital resources like soils, forests, organisms, fossil energies, and minerals) and that by depleting it a nation becomes poorer, not wealthier. In the presence of constraints dictated by resource availability, our economic assets will no longer be able to grow and will likely be forced to climax and decline. The "old" strategies, designed for times of growth on abundant resources, will no longer be applicable when resources become scarce and limiting. With abundant resources, efficiency is not important, and the dominant stratigy is to grow as fast as you can to grab as much as you can. However,as they become limiting the stratigy shifts to one of efficient and wise use. For example, Watt's engine was able to power the industrial revolution in the United Kingdom and Europe, in spite of its low efficiency (1%), thanks to the presence of abundant coal...efficiency was not an issue in those times and competition was a successful strategy. Instead, with resources becoming limiting, cooperation for increased efficiency and "more from less" seem to be more appropriate strategies for the near future. The limits will force us towards collaborative instead of competitive patterns and economies based on benefits for larger networks instead of for individual players. Some suggest that this is, for example, the case of circular economy, with rely on resource exchanges and recycling.

Many terms have been used to describe the economy “beyond capitalism” that would result from increased resource and network awareness, among which:

- a not-for-profit economy
- a regenerative economy
- a circular economy
- a sharing economy
- a living economy
- a purpose economy
- a post growth economy
- a sustainable economy
- a steady-state economy.
-

In light of the foregoing, we suggest the following:

- To be economic, the benefit of physical growth today must overcome an ever larger opportunity cost of depleted resources, displaced ecosystem services, displaced people, destroyed livelihoods, and ruined habitats of other species. The fact that these costs were often ignored did not make them go away. Our accounting must take these thing into account, otherwise we are lying to ourselves.

- The 7.5 billion inhabitants on Earth are all shareholders of planetary resources. This is hardly acceptable by today's economic and financial system, named by Peter Barnes "Capitalism 2.0" or "surplus capitalism" (Barnes, 2006). According to Barnes, "this system devours nature, widens inequality, and makes us unhappy in the process". Instead, if we are shareholders, we are entitled to receive the dividends of such property rights, in the form of goods and services for survival and wellbeing. Thus, equal access to resources becomes mandatory.

- The dividends of planetary property rights should be in a form that cannot be diverted nor diminished as often happens today with money flows subject to inflation and financially unequal tools. The planetary dividends should be managed by Governments, International Organizations, or independent Trusts, in order to provide a basis for community supplied health, food, and education (we might say, an equal share of resources). If a minimum income for all people is assigned, this might become the basis for further economic activities by each individual, once freed from survival worries.

- Redistribute wealth, not populations. Since real wealth is based on resources, the United Nations and governments must make sure that resources are distributed, traded and used fairly, in order to provide sufficient work potential and development opportunities to every nation, economic system, and individual. The emergy method proved to be capable of assessing potential trade imbalance from an environmental point of view, to complement monetary evaluations that only capture market dynamics and willingness to pay (Geng et al, 2017; Tian et al 2017a, b). Least Developed Countries (LDCs) need to be able to increase “value added” within their borders instead of sending emigrants chasing their resources and wages. Population migration should not be driven and forced by unfair resource appropriation and political turmoil, but left to free decisions of individuals and communities. Everyone has the right to stay in his/her country, to enjoy their own culture, roots, and community instead of being forced to find a living in other places having to endure life risks and untold suffering.

- Wealth disparity based on unfair exploitation of a country's or a population's resources and labor (according to the multifaceted and unjustified appropriation of land, technology and income by a few) should be replaced by equal development opportunities and agreements, strictly linked to appropriate resource use under the guidance and control by reformed international Institutions (United Nations, others...). In a way, as Daley (2005) has said, we need a "natural resource-ism" instead of "capitalism"...Examples may well be the Kyoto protocol (in spite of its limits) and the COP 21 efforts.

- We must do away with war…a simple method is to defund war, by sequestering funds and freezing funds that can be used to finance war and to outlaw the sale of arms to warring nations.

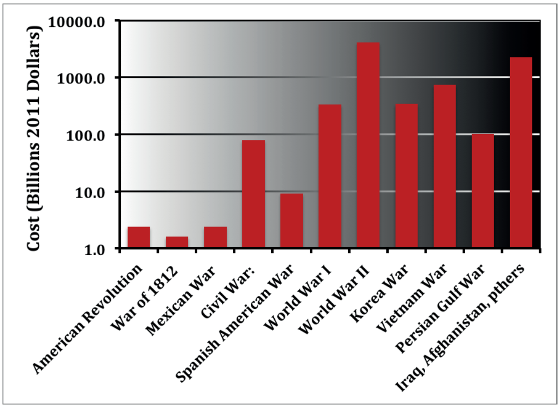

Figure 8. The cost of USA Wars. (Source Daggett, 2010)

The financial costs of war are demonstrated by Figure 8, which shows expenditures for wars in the USA since the American Revolution. While WWII was the most costly, at $4.1 trillion, the so-called "War of Terror" is soon to catch it and surpass it as the most costly (today standing at about $3.3 trillion). The absurdity of spending resources to tear down a society instead of building one seems lost on most humans. The fact that war is often… **"**driven by political corruption, disease, resource deprivation, overpopulation, urbanization, illiteracy, refugees, globalization, extremist ideology or some combination thereof …" (Greenwood & Hammes, 2009) seems to suggest that there are so many other more positive and far less costly ways of solving these issues.

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Sustainability and Well Being: Energy, Technology, and Complexity

Joseph A. Tainter

The common narrative about sustainability sees it emerging as a passive consequence of consuming less. This may involve a shift to clean, renewable forms of energy, as well as technological advances to find new energy sources, or develop more efficient ways of using existing ones. This presentation explores weaknesses in this narrative through the following points: (1) sustainability emerges from success at solving problems, not as a passive consequence of consuming less; (2) alternative energy sources are likely to yield lower net energy than fossil fuels; and (3) innovation is reaching diminishing returns, undermining the possibility that technology can forever offset resource depletion. We face no imminent crisis, but the long-term future is problematic.

Quantifying Human energy expenditure in cooking systems in rural areas in developing countries.

Karabee Das, Greeshma Pradhan and Sanderine Nonhebel

Energy is vital for day-to-day activities. It is strongly linked with human-beings and also to the economic development of a country. Households residing in rural areas in developing countries are mostly confined to solid biomass resources, mainly fuelwood. Women are the primary collectors of fuel for the households and a large share of their time is used for this. The traditional three stone openfire with wood as feedstock is very inefficient with respect to energy conversion. And deforestation due to the collection of fuel wood for cooking is a serious problem in rural areas. A lot of programs exist providing more efficient cooking systems and feedstocks to rural households, like improved cookstoves, charcoal and briquettes. However, in practice these systems are hardly implemented by the households. To understand why households are not implementing these energy efficient cooking systems, we analyse the human energy expenditure related to the most commonly used cooking systems for a village in Nepal.

We determine the amount of energy needed for cooking food in a rural household for a whole year. Then we determine the resources (wood, charcoal, briquettes) needed to provide this amount of energy given a certain technology (open fire, improved cookstove). Since briquettes and charcoal are made from wood, we calculated the amount of wood needed to make the briquettes and charcoal.

In the next step we determine and quantify the human activities needed to collect the energy in the 5 systems. So how many hours are needed to transport (headloads!) the wood from the forest to the village and what is the human energy expenditure for this.

It is shown that using an improved cookstove with wood is requiring the lowest amount of human energy, charcoal and briquettes require even more human energy than the traditional open fire system. This has to do with fact that a lot of labour is needed to convert the wood into charcoal and briquettes.

The results obtained in this analysis provide insights in why technologies are not accepted in the rural households. The working load of woman in rural areas is already high: technologies that require even more human labour are therefore not acceptable.

Emergy as a management tool for urban parks assessment

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São Paulo is a mega city which has been investing in the implementation of green areas to improve the population's quality of life. In this regard, the city council has been increasing the vegetation cover through an afforestation program and the creation of new urban parks. This work uses emergy synthesis to evaluate 73 parks in the city of São Paulo, and provides indicators to assess the environmental costs of their implementation and operation. (Fig. 1). The study quantifies the investment of society and nature in the operation and assessment of the environmental services produced by the group of parks, and answers what is the green / built ratio more favorable to provide the product set of an urban park.

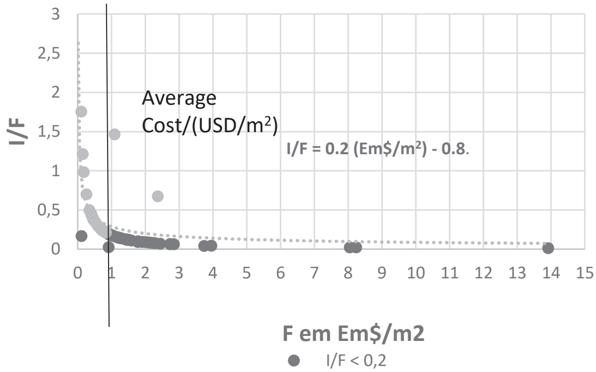

Fig. 1. Cost in Em$/m^2 and the I/F ratio of the municipal parks of São Paulo. The vertical line shows the real cost in dollars (1.11 USD/m^2), where grey dots to parks with I/F > 0.2) and black to parks with I/F < 0.2).

The results indicate that the maintenance of the installed infrastructure for leisure and education consumes more emergy than that employed to produce environmental services. Twenty-six percent of the parks have I/F less than 0.1 and 36% of the parks have 0.1 < I/F <0.2, which shows that the municipality should invest 5 to 10 times more emergy (F) for their maintenance than that provided by nature. This investment is directly proportional to the ratio between the green area and the built area of each park and there is no correlation with the amount of labor employed. The average Em$ values per square meter of the 73 parks is 0.55 Em$/m^2 corresponds to about 50% of the actual cost provided by the Secretary of the Green and Environment[1] (SVMA, 2010).

The ratio between the resources of nature and resources from the economy establishes an indicator for the management of existing urban parks that relates this ratio with the economic cost of one square meter of park, allowing to determine the best configuration for each park, prioritize actions for new projects and optimize the maintenance of old ones

[1] http://www.prefeitura.sp.gov.br/cidade/secretarias/meio_ambiente/ (access October 2016)

PORTFOLIO ANALYSIS AND ALLOCATION OF RENEWABLE SOURCES

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Abstract

We introduce a simplified model for the power output of renewable energy sources with tunable Gaussian correlated fluctuations and analyse the economic and emission impact of production fluctuations via Modern Portfolio Theory analysis, introduced by Markowitz. We show how – depending on the correlation patterns – a careful geographical allocation of renewal energy sources can reduce both the amount of energy needed for balancing the power system and its uncertainty. We then introduce an extended framework that allows for the optimization of a non-Gaussian portfolio of renewable energy sources whose production follows either historical weather datasets or synthetic time-series stochastic models. Analysis of time series together with such enriched frameworks would allow for the analysis of multiple realistic renewable generation scenarios helping decisions on the optimal size and spatial allocation of future energy storage facilities.

1 Introduction

The aim of this research is to demonstrate whether an optimal spatio-temporal allocation of renewable energy production could reduce the volume of electricity produced and sold through the balancing market [3] .

We introduce a simplified model for the power output of renewable energy sources with tunable Gaussian correlated fluctuations and analyse the economic and emission impact of production fluctuations via Modern Portfolio Theory analysis, introduced by Markowitz [2]. We show how – depending on the correlation patterns – a careful geographical allocation of renewal energy sources can reduce both the amount of energy needed for balancing the power system and its uncertainty. We then discuss the possibility of an extended framework that allows for the optimization of a non-Gaussian portfolio of renewable energy sources whose production follows either historical weather datasets or synthetic time-series stochastic models. Analysis of time series [1] together with such enriched frameworks would allow for the analysis of multiple realistic renewable generation scenarios helping decisions on the optimal size and spatial allocation of future energy storage facilities.

2 Model

In this section we describe a model for the allocation of renewable energy sources that follows the ideas of financial portfolio for optimal investments by Markowitz [2]. In sec.2.1, we introduce the portfolio model for renewable energy sources. We use sec.2.1.1 to build up some intuition on energy portfolios by describing the case of only two renewable sources with limited resources. In sec.2.2, we show that investment costs constrains can be safely introduced without changing the nature of the model. Finally, in sec.2.3 we analise a simple model of renewables plus traditional generation to show how an wise choice of the renewables' portfolio can help mitigate energy security issues.

2.1 Renewables Portfolio

We consider the case in which we have to allocate renewable electric power plants on $i = 1 \dots N$ sites; the maximum possible size on the $i-th$ site is W_i. To describe their energy production, we will assume that their unit production is described by a random variable p_i, with expected value $E(p_i) = e_i$ and variance σ_i describing their fluctuations, where $\sigma_i^2 = Var(p_i) = E\left[(p_i - e_i)^2\right]$. Notice that since we are considering electric generation, the produced power must exactly match the demand and any fluctuation respect to the forecasted values will require a balancing of the system. Hence, variance is strictly connected to the risk of diminished revenues or even economic losses.

The energy output of a plant will be $p_i w_i$, where w_i is the size of the i^{th} plant. Notice that the set $\mathcal{W}$ of possible allocations is constrained by the N inequalities

$$\mathcal{W} = \{w_i : 0 \leq w_i \leq W_i\} \tag{1}$$

and hence is a convex set. We will also refer to the vector $\vec{w}$ subject to the constrains 1 (i.e. $\vec{v} \in \mathcal{W}$) as an *energy portfolio* or, more simply, a *portfolio*.

Since we are considering renewable plants, their energy outputs will be correlated; at first order, we will describe such correlations by their covariance matrix $\boldsymbol{\sigma}$ with elements $\sigma_{ij} = E\left[(p_i - e_i)(p_j - e_j)\right]$. By definition, the correlation coefficient among variables i and j is $\rho_{ij}\sigma_i\sigma_j = \sigma_{ij}$. We can thus define the corresponding covariance matrix C:

$$C_{ij} = \sigma_i \rho_{ij} \sigma_j \tag{2}$$

Under such hypothesis, the total production from renewables will also be a random variable $P_R = \sum w_i p_i$ with expected value E_R and variance σ_R

$$\begin{aligned} E_R &= \sum w_i e_i \\ \sigma_R^2 &= \sum\sum w_i w_j \sigma_{ij} = \sum\sum w_i w_j \rho_{ij} \sigma_i \sigma_j \end{aligned} \tag{3}$$

. Hence, $E_R(\vec{w}) = \sum w_i e_i = \vec{w} \cdot \vec{e}$ is a linear functional of the allocation vector $\vec{w}$, while $\sigma_R^2(\vec{w}) = \vec{w} \cdot C\vec{w}$ is a quadratic form of the allocations $\vec{w}$ in the covariance matrix C. This is equivalent to considering a Markowitz portfolio with expected return $\vec{w} \cdot \vec{e}$ and volatility $\vec{w} \cdot C\vec{w}$

Notice that, since the attainable points (E_R, σ_R) are the image of a convex set $\mathcal{W}$ via linear and quadratic functions, they are also constrained to lie in a convex set $\mathcal{P}_R$ of feasible renewable energy productions. If we are interested to a high production with small uncertainties, the most efficient points will be located on the frontier of $\mathcal{P}_R$ as in fig.1.

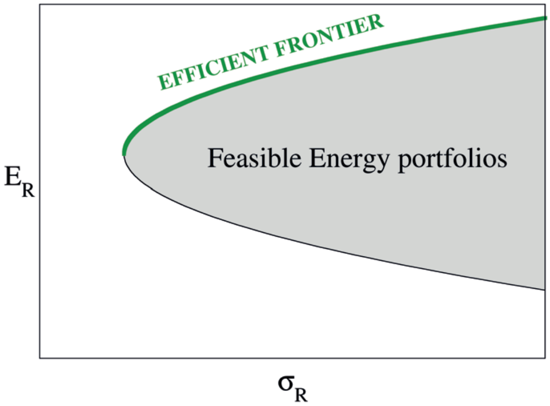

Figure 1: The set $\mathcal{W}$ of feasible energy portfolios is a convex set; hence, also the image of $\mathcal{W}$ in the plane of the expected energy productions E_R and variances σ_R is a convex set $\mathcal{P}_R$ (grey in the figure). Notice that at each point in the (E_R, σ_R) plane can correspond more than a portfolio. Best and worst portfolios have values on the boundaries of $\mathcal{P}_R$; in the figure, we show in green the *efficient boundary*. The choice of an optimal portfolio depends on the desired balance between the increasing revenues of higher expected energy production and the increasing costs associated with balancing fluctuations in the energy production.

2.1.1 Example

To have an intuition of the interplay among expected energy and the risk of fluctuations, let's consider the basic case of only two renewable power plants; in such cases, correlations are described by a single number $-1 \leq \rho \leq 1$. Moreover, let's assume that we have a limited amount of resources to distribute among the two plants subject to linear constrains $w_1 + w_2 = W$, i.e. $w_1 = w$, $w_2 = W - w$. Eq.3 then becomes:

$$\begin{array}{l} E_R = w_1 e_1 + w_2 e_2 \\ \sigma_R^2 = w_1^2 \sigma_1^2 + w_2^2 \sigma_2^2 + 2 w_1 w_2 \sigma_1 \sigma_2 \rho \end{array} \quad (4)$$

We notice that, since $\partial E_R / \partial \rho = 0$, the expected value of the produced power is not influenced by the fluctuations; however, since $\partial \sigma / \partial \rho \geq 0$, for a given resource allocation variance decreases with decreasing correlations and the minimum possible value is attained if renewables are maximally anti-correlated ($\rho = -1$). We show in fig.2 an example of the behavior of feasible portfolios in the case of two variables. Notice that while for two variables I can attain a maximal anti-correlation $\rho = -1$, this is not in general possible for many variables at the same time, i.e. it is not possible to attain $\forall i, j\ \rho_{ij} = -1$.

2.2 Convexity and Investment Costs

Let's consider the effects of the costs on the allocations. We have already assumed that physical, geographical and political constrains limit the size of the plants (i.e.

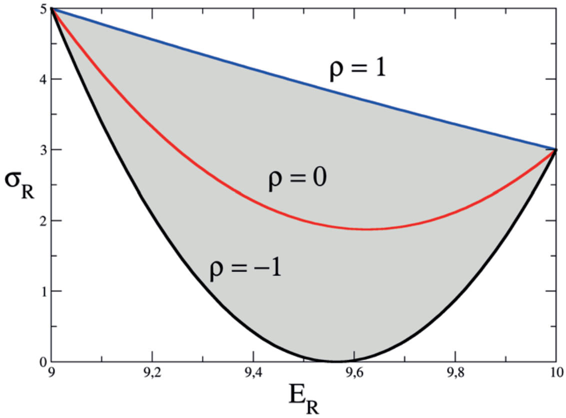

Figure 2: Example of two-resources allocation. For simplicity, we have chosen to vary the allocation w_1 in the interval $[0, 1]$ with $w_2 = 1 - w_1$. With this choice, there is a one-to one correspondence among (E_R, σ_R) and the two variables w_1, ρ; moreover, E_R assumes the two values e_1,e_2 for the extreme allocations $w_1 = 1, w_2 = 0$ and $w_1 = 0, w_2 = 1$. In the picture, we show a case in which the second plant has a lower expected production ($e_2 < e_1$) but both plants have the same variance. In such a case, since $\sigma_1 = \sigma_2$ it is possible to suppress fluctuations ($\sigma_R = 0$) when the productions of the two plants are totally anti-correlated ($\rho = -1$).

the portfolio) in the convex set $\mathcal{W}$ defined as the Cartesian product of finite intervals $0 \leq w_i \leq W_i$ of feasible sizes. On the other hand, the allocation of the plants will be naturally limited by a finite budget B, constraining the total investment cost to be $0 \leq \sum f_i(w_i) \leq B$, where f_i is the cost function associated to the $i^t h$ plant. If – as reasonable – the cost of each plant is a monotonic non-decreasing function, then also the set $\mathcal{B} = \{w_i : 0 \leq \sum f_i(w_i) \leq B\}$ of possible investments is convex. Thus, also the set of feasible points $\mathcal{F} = \mathcal{W} \cup \mathcal{B}$ (i.e. the feasible portfolios) is a convex set. Finally, the attainable productions $\mathcal{P} = \{(E(\vec{w}), \sigma(\vec{w})) : \vec{w} \in \mathcal{F}\}$ is a convex set, since it is obtained as the image of a convex set via a positive definite quadratic form; moreover, the images of optimal portfolios will allocated on the boundaries of $\mathcal{F}$.

2.3 Application to energy security

For simplicity, let's start from the case where we have a constant energy demand D to be satisfied by traditional energy plants – capable of a constant energy production E_0 – plus renewables; since demand and production must be always balance, the stochastic variable $\Delta = E_0 + P - D$ will represent the size of the balancing market.

To give an example, suppose that the average renewable production together is able to balance demand, i.e. average value $E_0 + E_R = D$; moreover, suppose that the balancing market is able to absorb fluctuations up to a size δ. Thus the probability $\alpha = Prob[-\delta \leq \Delta \leq \delta]$ that the balancing market is able to absorb fluctuations is a decreasing function of the renewables' production variance σ_R.

Notice that the probability that the market absorbs renewables' fluctuations can be calculated exactly as $\alpha = 1 - 2\,\mathrm{erf}\left(\delta/\sigma_R\right)$ if renewable plants' productions can be described to stochastic Gaussian variables; however, this would be an excellent estimate also in the case that I have a large number of productions p_i's described by non-Gaussian random variables with finite average and variance. Hence, the portfolios $\vec{w}$ that maximize security

$$\min_{\vec{w}\in\mathcal{F}} \mathrm{erf}\left(\delta/\sigma_R\left(\vec{w}\right)\right) \tag{5}$$

are exactly the ones that minimize $\sigma_R\left(\vec{w}\right)$.

2.3.1 Example: losses due to balancing market

To build a further intuition of the interplay between expected values, fluctuations and loss of revenues, let's consider again the basic case of only two renewable power plants with limited amount of resources subject to linear constrains $w_1 + w_2 = W$. We will suppose that, given an expected value E_R of energy production, it is always possible to sell it on the market at a price $c_0 \cdot E_R$; however, a penalty $c_1 \cdot |P_R - E_R|$ will be paid if the actual production P_R will differ from the expected one and that the price c_1 is much larger than c_0. Hence, the total revenue will be

$$R = c_0 \cdot E_R - c_1 \cdot |P_R - E_R| \tag{6}$$

; notice that R is a random variable with a probability distribution that will be in general more complicated than a simple Gaussian distribution. Under such conditions, it would be convenient to vary the allocations (w_1, w_2) among the two plants to reduce the penalty due to the higher cost of fluctuations; an example of such situation is shown in fig.3 where the curve of revenues is obtained by Monte-Carlo sampling.

3 Discussion

In this paper, we have introduced a portfolio model for the allocation of renewable sources. Our results indicate that, by using the anti-correlation often present among the fluctuations of different renewables, an optimal spatio-temporal allocation of renewable energy production could reduce the size of the electric power balancing market. Such reduction would lead to several beneficial consequences, like reducing the stress and the congestion on the power grids, maximizing their output by avoiding curtailment, lowering average energy prices on balancing markets, reducing the indirect carbon footprint of renewable sources and optimizing the hours of operations of renewable and conventional energy sources.

With the inclusion of investment and operative costs of renewable generation and related infrastructures (together with a 5-10 years forecast of trends in electricity demand), the above-mentioned framework could also be adopted as a tool to guide regulators, energy policies, and utilities in order to attain several goals, like focusing the development of non-programmable renewable resources towards the most effective locations and minimizing the amount of subsidies to renewable generative capacity necessary to reach a given emission reduction goal. Such a portfolio planning, by avoiding overcapacity and extending per-unit generation hours, would also improve the attractiveness of investment in subsidized renewable generation while providing incentives for the retirement of older and less efficient traditional power generation held for reserve. Finally, the use of portfolio models would allow to optimize the size and the

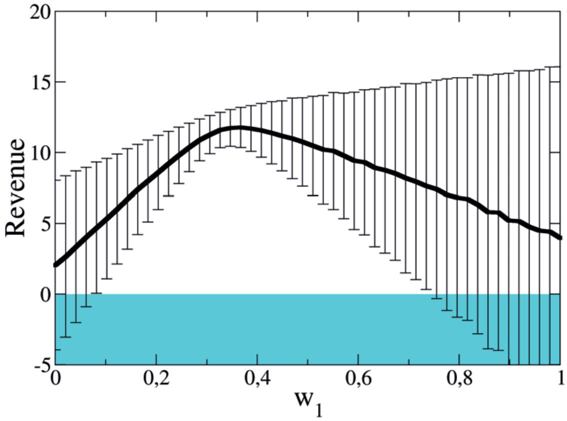

Figure 3: Example of revenue optimization for a two-resources allocation. For simplicity, we have chosen to vary the allocation w_1 in the interval $[0,1]$ with $w_2 = 1 - w_1$. The two plants have an expected production of $e_1 = 20$ and $e_2 = 10$ energy units and their productions are random variables with standard deviation equal to 10% of their expectations; moreover, we are in the ideal situation where fluctuations are strongly anti-correlated with $\rho = 0.95$. The plants productions are modeled as Gaussian variables with mean e_i and standard deviation σ_i; for the revenue function $R = c_0 \cdot E_R - c_1 \cdot |P_R - E_R|$ we have chosen a ratio $c_1/c_0 = 10$ among the prices. Using Monte Carlo sampling, it is possible to estimate the average value and the standard deviation of the revenues R.

spatial allocation of future energy accumulation facilities and to allow utilities to develop business models tailored according to the local distribution of renewable sources and storage systems.

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The Climate Change debate on Facebook: A clash of contrasting narratives beyond rational arguments

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Abstract

Despite the scientific evidences, anthropogenic climate change is still a strongly controversial subject. Since the subject is relevant for the well-being of future generations, it should be discussed on a neutral ground; however, denial campaigns in many nations enhance the polarization on the subject and often opposite views are linked to different political sides. In this paper, we show that the climate change controversy has generated two well separate and antagonistic echo-chambers on Facebook. To such an aim, we perform a quantitative analysis of such echo-chambers. Furthermore, we apply sentiment analysis to analyze the discussion topics. We find that the debate is not concentrated on more technical topics – the ones most relevant for the understanding of the phenomenon – but is much harsher on wide subjects like education or science. Hence, our analysis indicates that, on social media, the drivers of the actual debate are more emotional than rational. Given the importance of social media for the formation of personal opinions – especially in developed countries like the US, it is mandatory to find a strategy to dampen the debate and bring it to more scientific grounds.

1. Introduction

Anthropogenic climate change is the subject of controversy and a politically polarizing issue in many nations (McCright, Dunlap e T Marquart-Pyatt 2016) (Stokes e Carle 2015), especially those with organized denial campaigns (Farrell, Corporate funding and ideological polarization about climate change 2016). Such polarization is fostered by special interests and political elites (Farrell, Network structure and influence of the climate change counter-movement 2016) (Jasny, Waggle e Fisher 2015) and is facilitated by the growing use of new media where rival "echo chambers" form and diffuse competing information. Studies have examined these dynamics in the blogosphere (Elgesem, Steskal e Diakopoulos 2015), online comments (Martin e Rice 2014), and Twitter (Pearce, et al. 2014), but not Facebook. However, recent studies (Bessi, Coletto, et al. 2015) (Bessi, Petroni, et al., Homophily and polarization in the age of misinformation 2016) (Del Vicario, Bessi, et al. 2016) of Facebook users have demonstrated their tendency to form polarized groups of like-minded people (Garrett 2009). Immersed in these echo chambers, users frame and reinforce their worldviews (Bessi, Zollo, et al., Trend of Narratives in the Age of Misinformation 2015) (Sunstein 2002), acquire information confirming their preferred narrative even when containing intentional false claims (Bessi, Coletto, et al. 2015), and ignore dissenting information (Zollo, Bessi, et al. 2017).

2 Data Collection

The entire data collection process is performed exclusively by means of the Facebook Graph API (Facebook 2017), which is publicly available and can be used through one's personal Facebook user's account. We used only public available data (users with privacy restrictions are not included in our dataset). Data was downloaded from public Facebook pages that are public entities. Users' content contributing to such entities is also public unless the users' privacy settings specify otherwise and in that case, it is not available to us. When allowed by users' privacy specifications, we accessed public personal information. However, in our study we used fully anonymized and aggregated data. We abided by the terms, conditions, and privacy policies of Facebook.

We identified two categories of Facebook pages, a) supporting and b) denying Anthropogenic Global Warming (hereafter *Supporters* and *Denials*, respectively). We categorized pages according to their contents and self-description. The selection of sources has been iterated several times and verified by all the authors[1]. We collected all the posts (including related likes and comments) of such pages over a timespan of six years (Jan 2010, Dec 2015). The exact breakdown of the data is presented in Table 2.1.

Table 2.1: Dataset Breakdown

	Supporters	Denials	Total
Pages	72	53	125
Posts	163,882	338,176	502,058
Likes	16,025,772	10,192,992	26,218,764
Comments	699,390	2,260,633	2,290,023
Likers	3,224,638	1,310,535	4,460,974
Commenters	326,221	390,900	708,942

3 Results and Discussion

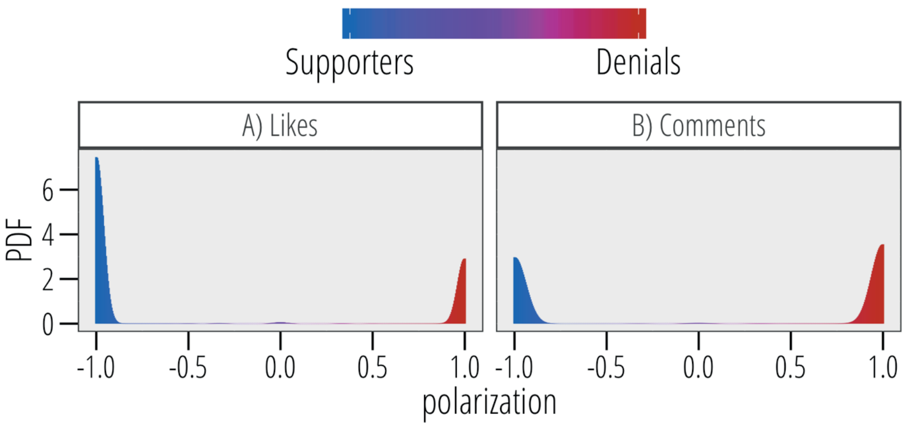
Polarization has been shown to be a pervasive phenomenon on social media (Thomas e O'Donnell 1994) (Gilbert, Bergstrom e Karahalios 2009). Indeed, confirmation bias plays a pivotal role in online social dynamics: users tend to join virtual echo chambers where they frame and reinforce their worldviews by interacting only with like-minded people, thus promoting and reinforcing group polarization (Myers e Lamm 1976) (Sunstein 2002) - i.e., the tendency of individuals to influence each other and form more extreme opinions.

In this paper, we examine the dynamics and nature of debate on climate change on Facebook. In particular, we perform a detailed comparative quantitative analysis of users' interactions with Facebook pages promoting distinct narratives on the topic. Our dataset is composed of the pages of 72 blogs supporting/promoting climate science (supporter pages) and 53 pages of blogs denying/questioning climate change and science (denial pages) covering a timespan of 6 years, a total of over 500K posts (see Table 2.1). Facebook actions of *likes, comments,* and *shares* have clearly different meanings from a user's viewpoint: a like represents positive feedback on a post, a share reflects willingness to increase the visibility of a post, and a comment is the way in which online debates takes form and may contain negative or positive feedback on the argument pointed out by the post.

[1] The complete list of Supporters and Denials pages is available at https://goo.gl/CbkqDJ

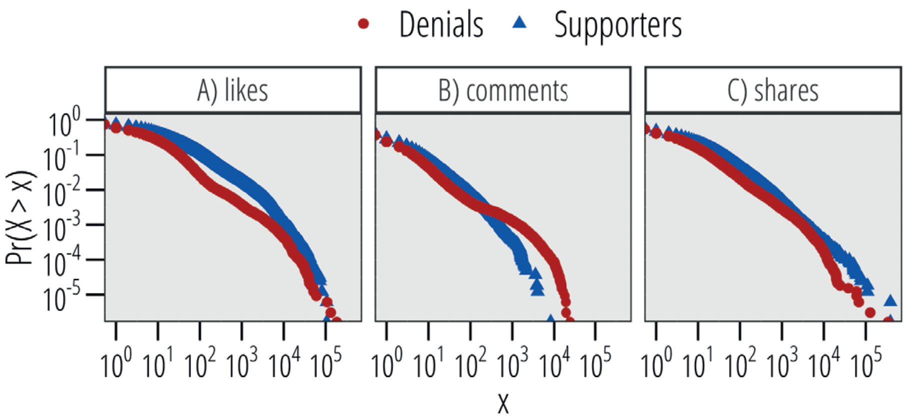
We first focus in at the level of individual users and characterize their activity across the different types of content. Specifically, for each user we count the total number of likes and comments on the posts supporting and denying climate science. To do this, we define users' polarization as the ratio of likes on one set of pages (supporting or denying) relative to the user's *total* number of likes. The closer the value to 1 (or -1) the more the user interacts mainly with one narrative. Fig. 1 shows the probability density function of users' activity on the two competing sets of pages and that distributions are sharply bimodal. The figure shows that users focus only on one type of content (supporting or denying) and ignore the other one. However, both denials' and supporters' posts to the climate change on Facebook do not generate significantly different consumption patterns: arguments of both narratives reverberate in a comparable way, even though the information belonging to the two narratives gets absorbed by different groups isolated from one another. Facebook users select their preferred climate change narrative and join virtual echo chambers in which they express and reinforce their personal views and opinions without interacting with the opposite version.

Fig. 1: Probability density functions (PDFs) of the polarization of all users computed both on likes (left) and comments (right).



To understand whether different contents lead to different users' online behaviors, we analyze the statistics of users' interaction with their echo-chamber information. In Fig. 2 we show how posts of the two competing climate change narratives are consumed in terms of number of likes, comments, and shares. The plots capture similar interaction patterns, as all distributions are heavy tailed. Thus, claims supporting and denying climate change reverberate in a comparable way and receive a similar amount of attention on the Facebook platform. Consumers of both types of information interact with their preferred content is a similar way.

Fig. 2: Complementary cumulative distribution functions (CCDFs) of the number of comments, likes, and shares received by posts belonging to Denials (red circles) and Supporters (blue triangles) pages.



The circumstances might bias the social perception on this relevant global issue. Indeed, the tendency of users to focus on their favorite narratives and form polarized groups might alter the way certain topics are digested. Moreover, debating with like-minded people has been shown to negatively influence their emotions and to burst group polarization (Zollo, Novak, et al. 2015) (Spears, Lea e Lee 1990).

Our analysis provides evidence also in the case of the climate change debate, the consumption of content on Facebook generates an echo-chamber like structure: users tend to focus on one narrative and to ignore the other. Such a segregated pattern might be driven by the way contents are presented to the users to match their preferences: users in different echo-chambers will have different perceptions regarding the same subject. To shade light on this aspect and to measure the distance among the sentiment of the users respect to the same topic, we analyze how the subject of a post is presented to the users.

To perform the analysis, we make use of IBM Watson™ AlchemyLanguage service API[2] that allows to extract semantic meta-data from posts content. Such a procedure applies machine learning and natural language processing techniques aimed to analyze text by automatically extracting relevant entities, their semantic relationship as well as the emotional sentiment they express (Gangemi 2013).

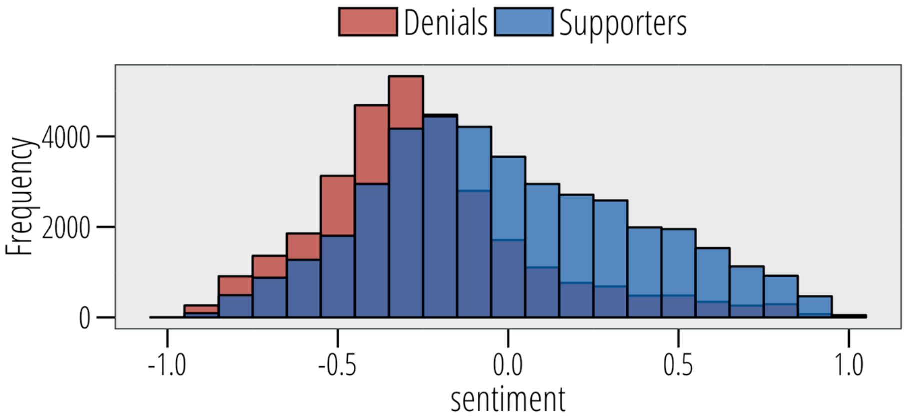
In particular, we extract the main concepts and sentiment presented by each post of the dataset, whether it has a textual description or a link to an external document. The AlchemyAPI tools make use of the language patterns surrounding the input text looking for signals that indicate sentiment and exploring information based on the concepts behind such an input. Thus, a concept is a high-level conceptual

[2] http://www.alchemyapi.com

association identified in the content provided as input to the service. Input content is auto-tagged against a concept graph, that formally represents the relationships between the concepts contained in the data on which it is based.

Fig. 3 shows the sentiment distribution of posts on both Supporters and Denials pages. The sentiment is defined in the range [-1,1], where -1 is negative, 0 is neutral, and 1 is positive. We may observe a slightly negative overall pattern for both categories, although clearly more pronounced for Denials than for Supporters pages. Notice that we consider how subjects are presented in a post and we do not take into account the sentiment that the post may elicit in the reader, or the sentiment of users involved in the discussion.

Fig. 3: Sentiment distribution of posts on Denials (red) and Supporters (blue) pages.

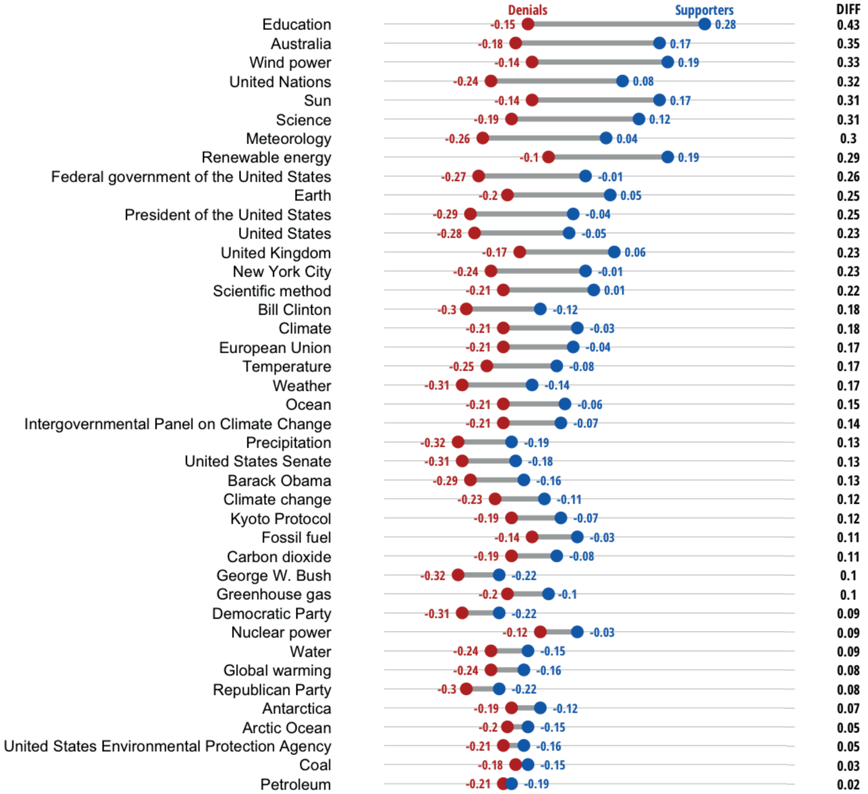


The online discussions as well as the framing of the specific narrative evolve around different topics. To make explicit how the Supporters and Denials echo chambers perceive the different debated issue, we focus on topics extracted from the posts on pages of both narratives.

Looking at the top-100 concepts of each echo-chamber, 44 concepts are shared by both communities. Such concepts are shown in Fig. 4: for each concept, we compute its average sentiment - i.e., the mean of the sentiment of all the posts where it appears. Concepts are rank-ordered by the difference between the average sentiment on Supporters posts and that on Denials posts. Thus, concepts at the top are those discussed with the greatest difference in sentiments, while those the bottom are discussed in a much more similar way on both sets of pages.

The overall set of 44 topics resulting from the analysis reflects contemporary debates over climate change. They tend to be issues that previous investigations (Boussalis e Coan 2016) have shown to be raised by denialists in reaction to climate science and policy-making and thus sources of contention between the two camps. These include numerous topics concerning scientific evidence for anthropogenic climate change, including alternatives to greenhouse gas emissions (e.g., sun, climate, temperature, oceans, carbon dioxide); the role of scientific expertise (education, science, scientific method); climate change politics and policy-making (including government bodies from the UN to the US Environmental Protection Agency as well as political parties and leaders); and energy sources and industries (wind power, renewables, nuclear, coal and petroleum).

Fig. 4: Sentiment distribution of posts on Denials (red) and Supporters (blue) pages.



Our results reveal that these 44 topics are embedded in posts reflecting very different sentiments: universally negative on denial pages but less so and often positive on supporter pages. The posts showing the greatest distance in sentiments on the two echo chambers are education (likely reflecting criticisms of scientific expertise by self-proclaimed "citizen scientists" on denial pages), Australia (where climate policies have been very salient and played a role in recent elections), wind power (promoted by supporters and ridiculed by denialists), United Nations (a frequent target of denialists for its role in promoting climate policies), sun (a favorite alternative to GHG emissions for denialists) and science (a constant source of battle in climate debates, with denialists questioning findings and methods). In contrast, those showing the lowest distance in sentiments are Antarctica, Artic Ocean, U.S. EPA, coal and petroleum. While the state of ice in the two polar regions is often debated, the debates tend to be softer than those over the role of the sun, temperature trends, etc. It is very interesting that more technical topics do not yield strong emotional divides on Facebook pages, despite their importance: this is the case of the very controversial efforts of EPA to regulate GHG emissions, or the future use of petroleum and especially coal.

4 Conclusions

Our findings pose important warning about the way climate change contents get consumed on Facebook. Indeed, we show that users mainly focus their attention on one of the two narratives and do not engage with the other one. On Facebook climate change discussions are really polarized by the framing of the narrative and on the diverse presentation of concepts. Indeed, such a distance may be a key marker to locate controversial topics and to understand the evolution of the core narratives within distinct echo chambers. Our new measures could be of great interest to identify the most crucial topics in online debates. Indeed, it is highly likely that the greater the emotional distance between the same concept in two echo chambers, the greater their polarization effect on users.

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Assessment of Renewable Energy Expansion in the Java-Bali Islands, Indonesia

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Abstract

Many developing countries face a dilemma between meeting the intensive growth in electricity demand, broadening an electricity access, as well as tackling climate change. The use of renewable energy is considered as an option for meeting both electrification and climate change objectives. In this study, long-term forecasting of electricity supply for the Java-Bali power system – the main power system in Indonesia – is presented. The forecasts take into consideration the Indonesian government policy of increasing the share of new and renewable energy in the national energy mix up to 23% by 2025 and 30% by 2050. After a systematic review of energy system models, we perform the analysis of the Java-Bali power system expansion using the Long-range Energy Alternative Planning system (LEAP) model. Three scenarios are developed over the planning horizon (2016-2050) including the business as usual scenario (BAU), the renewable energy scenario (REN) and the optimization scenario (OPT). The results of the three scenarios are analyzed in terms of the changes in resource/technology deployment, CO_2 emissions and total costs.

1. Introduction

Indonesia is the fourth most populated country in the world with a continuous economic growth. The stable economic growth correlates with the increased demand for electricity. The growth of electricity demand has been 7.8% per year on average over the period of 2010-2014 (PLN, 2015). Further, electricity demand is estimated to more than double by 2025 (PLN, 2015). Indonesia's electricity demand is mainly met by fossil fuel-based power generation. In 2015, fossil fuel constitutes 90% of the national power production (PLN, 2016a). To reduce its reliance on fossil fuels, under the most recent National Energy Policy (NEP), the government of Indonesia (GOI) sets a target to increase the share of new and renewable energy in the national primary energy mix up to 23% by 2025 and 31% by 2050 (Government of Republic of Indonesia, 2014). This paper analyzes plausible scenarios of the NEP implementation in the power sector. We focus on the Java-Bali power system, which generates 74% of the national electricity supply in 2015 (PLN, 2016a).

2. Methodology and Data

2.1. Methodology

2.1.1. Systematic selection of energy system model

To select a model that suits most with our analysis needs, we conducted a systematic selection process on numerous energy system models. We filter the models to identify only the ones that are suitable for analyzing a long-term power system expansion considering technical, economical, and CO_2 emissions parameters. Given these criteria, LEAP (the Long-range Energy Alternatives Planning System) has several advantages including its ability to accommodate various characteristics essential for an energy sector analysis in developing countries (Urban et al., 2007), its open access policy, and its user-friendly characteristic.

2.1.2. Validation of the selected energy system model

LEAP was developed at the Stockholm Environment Institute. LEAP is able to perform energy demand analysis with end-use based approach at the disaggregated level. LEAP provides a range of accounting, simulation and optimization methodologies for modeling electric sector generation and capacity expansion planning (Heaps, 2016).

We validate the LEAP model by using the historical data on the Indonesian electricity demand and power production recorded by the National Electricity Company (PLN) during the period of 2005-2015. The validation results demonstrate that the level of LEAP accuracy ranges between 97.5% and 100%.

2.1.3. Development of scenarios of power capacity expansion

We develop scenarios for capacity expansion during the period of 2016-2050 based on different assumptions. Firstly, the business as usual scenario (BAU) assumes a continuity of the present state of power generation technology deployment in which dominated by fossil fuels. Secondly, the renewable energy scenario (REN) assumes an increased deployment of renewable energy technologies in order to meet the NEP targets. Nuclear is also considered as new technology to be employed after maximum use of renewable energy (Government of Republic of Indonesia, 2014). Thirdly, the optimization scenario (OPT) seeks for a least-cost solution to meeting the NEP targets. The BAU and REN scenarios employ the accounting method of LEAP, while the OPT scenario uses the optimization method of LEAP.

2.2. Data

Electricity demand projection for the year 2016 to 2025 is calculated based on the estimated demand growth in the Electricity Supply Business Plan 2016-2025/RUPTL (PLN, 2017). The demand projection for the remaining years (2026 to 2030) is based on the assumption that demand for electricity continues to grow at 7%, which is the estimated growth rate in the year 2026. Transmission losses are assumed to gradually decrease from 8.6% to 7.9% between 2015-2030 (KESDM, 2015). The annual load data was collected from the Java-Bali dispatcher unit (P2B, 2016). We set the planning reserve margin at 35% in accordance with the criteria in the National Electricity General Plan 2015-2014/RUKN (KESDM, 2015). Table 1 presents the renewable energy potentials to be exploited for the power capacity expansion. Meanwhile, characteristics of the employed technologies are listed in Table 2.

Table 1: Renewable energy potential. Source: [a](DEN, 2016b); [b](PLN, 2017)

Renewable	Potential in Gigawatt[a]	
	Total Indonesia	Java- Bali
Hydro	75	4.2
Hydro pumped storage	data not available	3.9[b]
Mini hydro	19.4	2.9
Geothermal	17.5*	6.8*
Biomass	30	7.4
Solar	207.9	33.1
Wind	60.6	24.1

*excluding the speculative and hypothetical potential

Table 2: Characteristics of technologies in the Java-Bali LEAP model

Technology	Lifetime (years)[a]	Efficiency (%)[b]	Availability (%)[c]	Capacity credit (%)*[d]	Capital cost (US$/kW)[b]	Fixed O&M cost (US$/kW)[b]	Variable O&M cost (US$/MWh)[c]
USC coal	30	44	80	100	1867	64	3.8
Natural gas combined cycle	25	57	80	100	817	24	3.8
Natural gas open cycle	25	38	80	100	439	21	3.8
Hydro	35	100	41	51	2200	56	3.8
Mini hydro	35	100	46	58	3350	67	3.8
Hydro-pumped storage	35	95[c]	20	25	1050[c]	54[c]	3.8
Geothermal	20	10	80	100	2675	53	0.7
Solar PV	20	100	17	22	1953	20	0.4
Wind power	20	100	28	35	1756	44	0.8
Nuclear	40[f]	33	85[g]	100	3967	164	8.6[g]
Biomass	20[h]	35	80	100	2228	78	6.5

*Capacity credit in LEAP is defined as the fraction of the rated capacity considered firm for calculating the reserve margin (Heaps, 2016).
[a]IEA (2015); [b]OECD/IEA (2017); [c]DEN (2016a); [d]calculated based on the ratio of availability of the intermittent plant to the availability of a standard thermal plant Heaps (2016); [e]PLN (2016b); [f]Rothwell (1996)[;] [g]IEA and NEA (2015)[;] [h](IRENA, 2012); [i]ACE (2016).

3. Results and Discussion

3.1. Business as usual scenario (BAU)

In BAU, coal remains the dominant technology, followed by natural gas (Figure 1). Together they constitute 88% of the total capacity of the Java-Bali power system in 2025 leaving only 12% share for the renewable energy. Despite the full utilization of the geothermal and hydro potentials of the Java-Bali islands, the share of the renewable capacity is lower in 2050 than in 2025 i.e. 5%. This is because the potential for both geothermal and hydro in Java-Bali is limited. Yet, this scenario neither introduces other renewable technologies nor nuclear technology. Consequently, the power production within the Java-Bali system remains dominated by fossil fuels, which constitute 92% and 97% in 2025 and 2050 respectively.

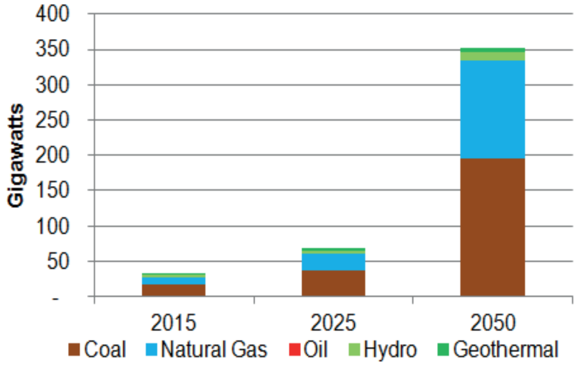


Figure 1 Capacity mix under the BAU scenario

3.2. Renewable energy scenario (REN)

Phase 1: 23% power production from new and renewable energy by 2025

In 2025, the capacity of renewable energy expands up to 22.4 GW or nearly three times higher compared to BAU. This consists of hydro (7.6 GW), geothermal (5.3 GW), biomass (2 GW), wind (2.5 GW) and solar (5 GW). Renewable energy constitutes 30% of the total capacity of the Java-Bali power system. Meanwhile, the capacity of coal decreases to 37% when compared to 76% in BAU. Despite its significantly reduced capacity share, coal remains the major source of power production i.e. 55% (Figure 2a) due to its relatively high capacity factor compared to the capacity factors of hydro, wind and solar PV.

Phase 2: 31% power production from new and renewable energy by 2050

As follow-up of phase-1, the renewable energy capacity continues to expand, hence in 2050 the renewable capacity reaches 82 GW, comprised of hydro (11.7 GW), geothermal (6.1 GW), biomass (7.4 GW), wind (24 GW), and solar PV (33 GW). In compliance with NEP, the power production from new and renewable energy resources increases up to 31% in 2050 (Figure 2b), owing to the maximum utilization of renewable energy potentials of the Java-Bali islands and the deployment of nuclear power. Nuclear deployment is inevitable considering that the renewable energy alone could not deliver the 31% target. At the same time, the share of power production from coal decreases down to 29%, while the share of natural gas rises up to 39%.

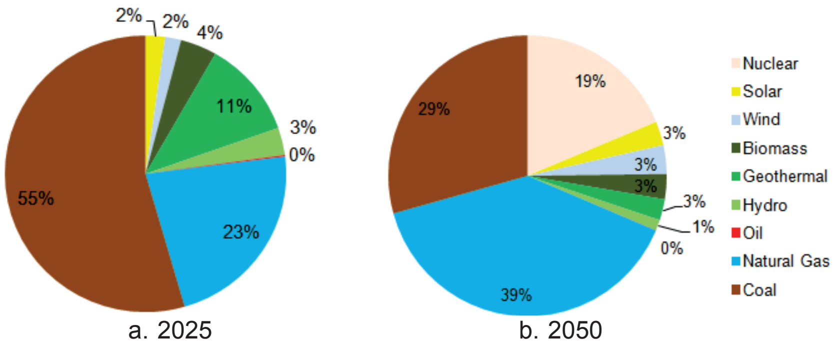


Figure 2: Power generation mix under the REN scenario

3.3. Optimization scenario (OPT)

Phase 1: 23% power production from new and renewable energy by 2025

In 2025, the renewable capacity expands up to 14.9 GW, i.e. nearly doubles when compared to BAU. It consists of hydro (5.3 GW), geothermal (3.9 GW), biomass (4.7) and wind (1GW). Together they constitute 22% of the total capacity of the Java-Bali power system. The power production shares between coal, natural gas and renewables are similar with the one in REN phase 1 (Figure 3a). In conformity with NEP, the renewable share reaches 23% while natural gas and coal constitute 22% and 55% of the Java-Bali power production, respectively.

Phase 2: 31% power production from new and renewable energy by 2050

In 2050, the capacity of renewables reaches 45.2 GW or 12% of the total capacity of the Java-Bali power system. These capacities result in 10% of the power production in 2050 (Figure 3b). To fill the gap to 31% new and renewable share as required by

NEP, nuclear power are added from 2031 onward so as in 2050 the capacity of nuclear reaches 52 GW and contributes 21% of the total power production.

The OPT scenario optimizes the choices of both technology to be added and power plants' dispatch based on their respective costs. Hence, the changes in the cost assumptions of power generation technologies may lead to different results. The results from cost optimization do not necessarily represent the preferences of policy makers or energy planners. Indeed, the capacity expansion to achieve 23% and 31% new and renewable energy shares in the electricity production mix can be cost-optimized. However, compared to the "what if" scenario (REN), OPT results in different types of renewable technology being deployed. In this scenario, solar PV does not appear in the capacity mix. This indicates that solar PV is not competitive compared to other technologies given current solar technology costs. Clearly, it is likely to change if the simulations include technological progress of PV technology, which is a subject for our future work.

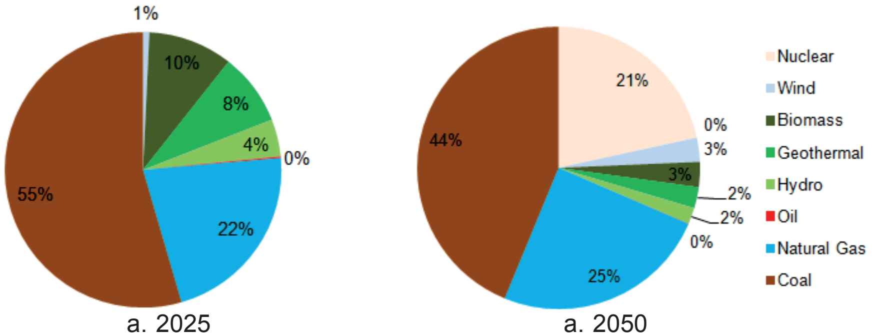


Figure 3: Power generation mix under the OPT scenario

3.4. CO_2 emissions

When the power capacity expansion continues under the BAU technology mix, the corresponding CO_2 emissions double in 2025 and become nine-fold in 2050 in comparison to 2015 (Figure 4) These result in carbon intensities of 747 g/kWh and 689 g/kWh in 2025 and 2050, respectively. The implementation of NEP reduces the carbon intensity to 605 g/kWh in 2025 and 388 g/kWh in 2050 under the REN scenario. Meanwhile, under the OPT scenario the carbon intensities in 2025 and 2050 are 602 g/kWh and 447 g/kWh, respectively.

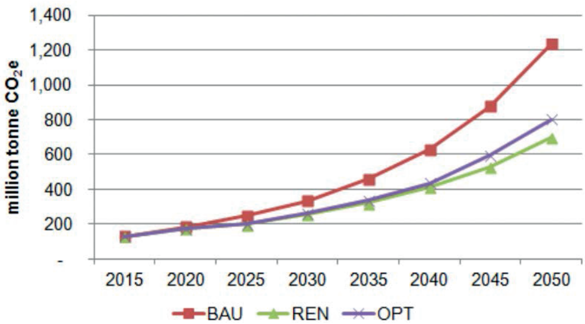
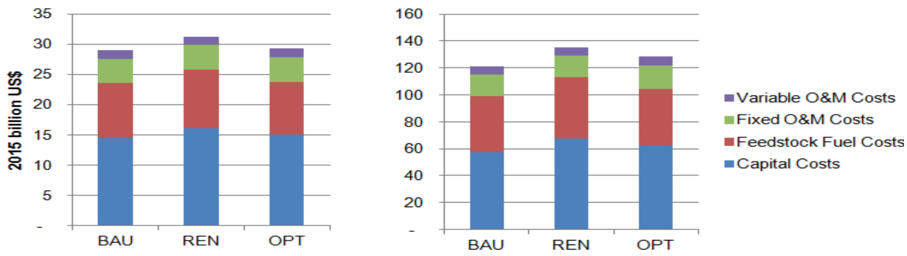


Figure 4: CO_2 emissions in different scenarios

3.5. Cost of Capacity Expansion

Cost of power capacity expansion consists of capital costs, variable operation and maintenance (O&M) costs, fixed O&M costs and fuel costs. In BAU, the total capacity expansion costs reaches 29 billion US$ by 2025 (Figure 5). These costs are equal to 0.14% of the cumulative Indonesian GDP during 2016-2025[1]. They increase up to 121 billion US$ by 2050, which is equal to 0.09% of the cumulative Indonesian GDP. Compared to the costs of BAU in 2025 and 2050, the total costs of REN are 9% higher in 2025 and become 12% higher in 2050. In the OPT scenario the total costs increase 0.4% and 6% in 2025 and 2050, respectively when compared to BAU at the same period.



a. 2025 b. 2050

Figure 5: Costs of power capacity expansion in different scenarios

4. Conclusions

This paper analyzes plausible scenarios of capacity expansion for the Java-Bali power system taking into consideration the NEP targets. After a systematic selection of different models, we choose the LEAP model to perform the analysis. At first, the model is validated using the actual data of the Indonesian power system. Then, three sets of scenarios of the power system expansion for the period 2016-2050 are developed and analyzed.

In the case when the power capacity expansion continues in the present state, the projected future power generation is dominated by fossil fuels. The alternative scenarios allow the achievement of the NEP targets. In the REN scenario, the NEP phase-1 target is achieved through the expansion of hydro and geothermal capacities as well as introduction of biomass, wind and solar PV technologies. Meanwhile, the accomplishment of phase-2 target involves maximum utilization of renewable energy potentials of the Java-Bali islands with an addition of nuclear power capacity. The cost-optimization scenario (OPT) shows nearly similar results, but solar PV does not appear in the capacity mix whereas nuclear power share in 2050's power production is higher than in REN.

CO_2 emissions in 2050 become nine-fold of the value in 2015 in the BAU scenario. These emissions are reduced nearly half in the alternative scenarios. However, the alternative scenarios results in higher investment costs.

[1] Assuming annual GDP growth of 4.5%

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Energy and mobility: Hydrogen as fuel for mobility and storage for renewable energy

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Abstract

Currently passenger car transport is mainly based on fossil fuels and internal combustion engine vehicles. However, using this technology we are facing different problems such as increasing air pollution and greenhouse gas emissions as well as problems related to energy supply security. For heading towards a more sustainable transport system alternative fuels, based on renewable, CO2-poor or CO2-free sources of energy, and alternative automotive systems are of central importance. The most environmentally friendly vehicles discussed nowadays are battery electric vehicles and fuel cell vehicles powered by hydrogen. These vehicles are zero-emission vehicles at the point of use and this is big advantage especially for their use in urban areas. In the case that electricity and hydrogen are produced from renewable energy sources BEVs and FCVs could significantly contribute to the reduction of GHG emissions.

The core objective of this paper is to provide an appraisal of the prospects of hydrogen in FCVs up to 2050. We have considered whole energy supply chain including different primary energy sources for hydrogen production. In addition the role of hydrogen as storage for surplus electricity from RES is discussed.

1. Introduction

Current passenger car transport is mainly based on fossil fuels and internal combustion engine (ICE) vehicles. However, using this technology we are facing different problems such as increasing air pollutions and greenhouse gas (GHG) emissions as well as problems related to energy supply security. For heading towards a more sustainable transport system alternative fuels – based on renewable, CO2-poor or CO2-free sources of energy – and alternative automotive systems are of central importance, see e.g. (IEA, 2011).

The most environmentally friendly vehicles discussed nowadays are battery electric vehicles (BEVs) and fuel cell vehicles (FCVs). These vehicles are zero-emission vehicles at the point of use what is a big advantage especially for their use in urban areas.

The core objective of this paper is to provide an appraisal of the prospects of hydrogen in passenger cars up to 2050 from an economic, ecological and energetic point of view. We have considered whole energy supply chain including different primary energy sources for hydrogen production.

2. Hydrogen as a fuel for mobility

Hydrogen is considered as one of the cleanest and most innovative energy carrier to supply energy services - mobility. It is the simplest, lightest and most abundant element in the universe. It constitutes about three-quarters of the mass of the universe, but it does not exist on the earth in elemental form in quantities associated with energy use. However, it can be produced from different energy sources: fossil energy, nuclear energy as well as renewable energy sources (Ajanovic, 2006).

Hydrogen has the potential to reduce greenhouse gas emissions, climate change, global warming, and to increase energy diversity and supply security. In the last fifteen years the number of hydrogen refueling stations and vehicles is growing. However, currently worldwide there are only few FCVs in use (OECD, 2012).

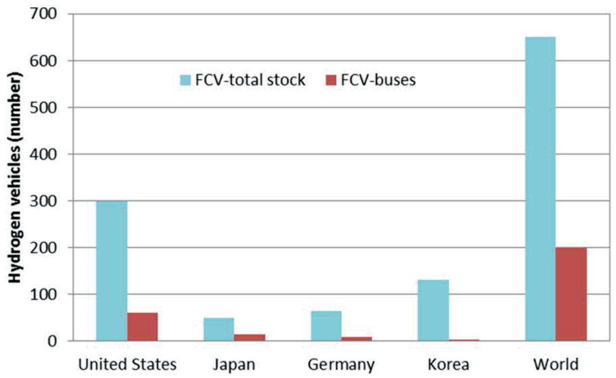

Fig. 1. Total stock of hydrogen FCV in today's leading countries and worldwide

The major reasons for such development are limited infrastructure and especially high investment costs for FCVs. The cost of FCVs and BEVs are already declining and could be significantly reduced in the future through technological learning, see Fig. 2.

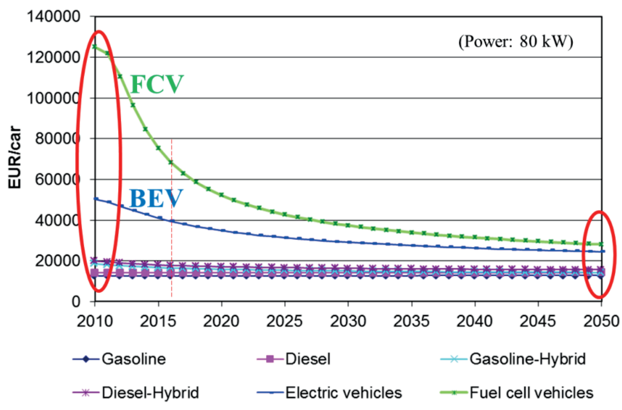

Fig. 2. Possible cost reductions trough technological learning

Today, the largest part of hydrogen, about 60%, is directly produced from fossil fuels and about 40% of it is a by-product of the petrochemical industry and the electrolysis for chlorine production. The steam reforming of natural gas is mostly used process for hydrogen production and has been used in chemical, petroleum and other industries process for years.

All advantages of hydrogen are available only if hydrogen is produced from renewable energy sources (RES) and this is worldwide a long term vision of hydrogen. The different processes of hydrogen production from renewable energy sources can be grouped into three categories: thermal, electrochemical and biological process. Some of these processes are well developed and some are still under fundamental research. Water electrolysis is well developed technology. Although, gasification of coal is one of the oldest methods for hydrogen production, gasification of biomass needs additional improvements. All biological processes are still under fundamental research (NHA, 2004).

In this paper hydrogen production by electrolysis with electricity from renewable energy sources, and steam reforming of natural gas is analyzed.

Total CO2 emissions of FCVs per kilometre driven are in the range from 13 to 125 g CO2/km, depending on the primary energy sources used for hydrogen production. Since investment costs for vehicles have the largest impact on the total transport costs, the costs per kilometre driven for all energy chains analysed are almost the same. These costs are much higher than in case of conventional ICE vehicles, so that currently FCVs are not competitive. However, in the future mostly due to reduction of the investment costs for vehicles the mobility costs of FCVs could be much closer to that of conventional vehicles, see Fig. 3.

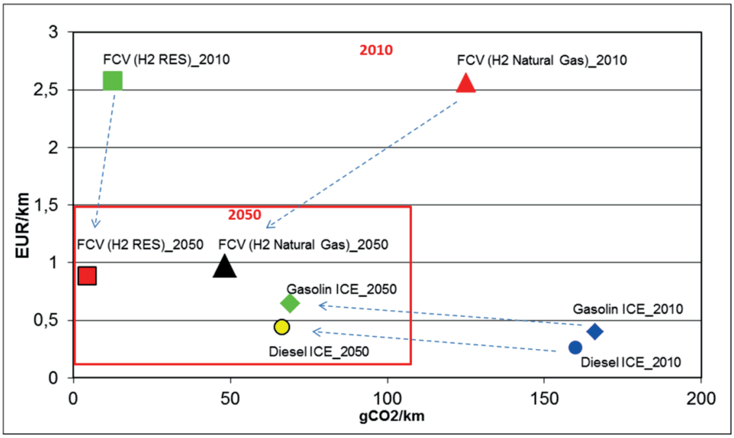

Fig. 3. Comparison of specific CO2 emissions and driving costs of FCVs and ICE vehicles in 2010 and 2050 (based on Ajanovic et.al., 2011)

3. Hydrogen as storage

The global energy system faces currently two major challenges. On the one hand it is important to have sufficient and secure energy supply. However, at the same time, it is important to reduce energy-related greenhouse gas emissions (GHG) and to move towards more sustainability by increasing the use of renewable energy sources (RES). The key goals of the EU climate and energy policy are mitigation of global warming, improvement of air quality and reduction of energy consumption. The requirements of strategies for the transformation of current energy systems towards more sustainable ones include among other measures further technical developments of the concepts of converting renewable power into easy storable energy carriers such as hydrogen and methane, as well as implementation of the corresponding supporting policies.

Due to the supporting policy measures in the EU the share of RES in total energy supply is continuously increasing. In the last years, especially high PV and wind penetration in some regions has been noticed. However, the use of intermittent RES for electricity production leads to the need for increased balancing activities between supply and demand to meet the so-called residual load, see Fig. 4.

The important issue is how these changes in the residual load will impact the price of electricity on the wholesale spot markets. The effects on electricity prices are shown in Fig. 4 where a hypothetical scenario of high levels of electricity generation from wind, PV and run-of-river hydro plants over a week in summer is depicted using synthetic hourly data for an average year in Austria. The graph shows significant volatilities in electricity market prices with total costs charged for conventional capacities fluctuating rapidly from zero to 14 cents/kWh (black solid line). In practice, of course, prices may not only go to zero but even become negative, (Haas&Auer, 2013).

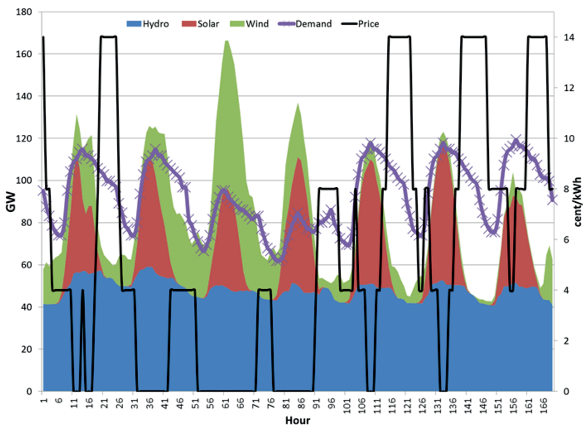

Fig. 4. Example: Development of intermittent renewables from wind, PV and run-of-river hydro plants over a week in summer on an hourly base in comparison to demand and resulting electricity market prices with total costs charged for conventional capacities (Haas&Auer, 2013)

Hence, in peak-demand periods for residual load the price of electricity is significantly higher than in periods where excess electricity is available, see Fig. 4. With the increasing use of PV and wind for electricity generation, also increasing amounts of cheap or even free surplus energy is sometimes available (IEC, 2011). This surplus electricity can be used directly in electric vehicles.

Although the number of electric vehicles is increasing, number of rechargeable electric vehicles (Battery Electric Vehicles, Range Extender Electric Vehicles and Plug-in-Hybrid Electric Vehicles) is still very low, about 1, 3 million. One of the major reasons for such development is the limited driving range of electric vehicles. The operating range of BEV is still relatively low, mostly about 100 to 150 km. This is a major reason for the low acceptance of these vehicles. For the future, a more interesting type of EVs is the fuel cell car. It is powered by hydrogen and already now, in the immature stage of this technology, they have operating range between 200 and 690 km (Mazloom&Gomes, 2012).

In addition to the hydrogen use as a fuel for mobility, it can be also used as storage for electricity. A typical hydrogen storage system consists of electrolyzer, compressor, a hydrogen storage tank and a fuel cell, gas motors, gas turbines or combined cycles of gas and steam turbines for electricity generation from hydrogen (IEC, 2011; Felberbauer et al., 2012), see Fig. 5. Hydrogen can be stored as a gas under pressure, a liquid at very low temperature, adsorbed on metal hydrides or chemical bonded in complex hydrides. However, for stationary applications gaseous storage under high pressure is the most popular choice (IEC, 2011).

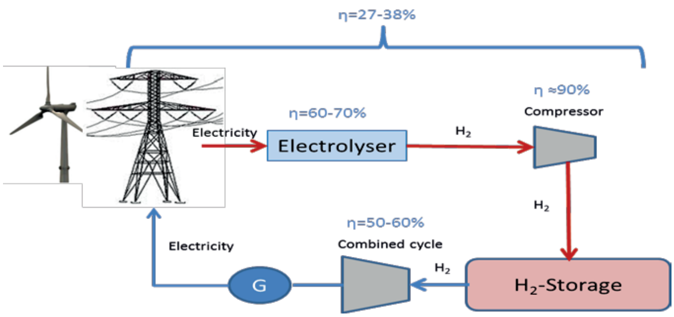

Fig. 5. Energy supply chains: Hydrogen as a storage for electricity from RES

Hydrogen can be stored much easier than electricity, and it can be re-electrified if required in times of lack of RES-E generation. However, one of the main problems of energy carriers are the losses occurring in the whole energy supply chain. The energy losses depend on the efficiency of the conversion process at the each transformation stage as well as efficiency of the finally used technology. The efficiency of the electrolysis is in the range from 60-82%. Efficiency of compressing and storing hydrogen is in the range from 85 to 95%. For example, total efficiency of the energy chain shown in Fig. 2 is between 27 to 38%. The energy losses due to converting hydrogen into electricity are between 40 and 50% (Felberbauer et al., 2012). These additional losses can be avoided if hydrogen is used directly, for example in the transport sector, see Fig. 6.

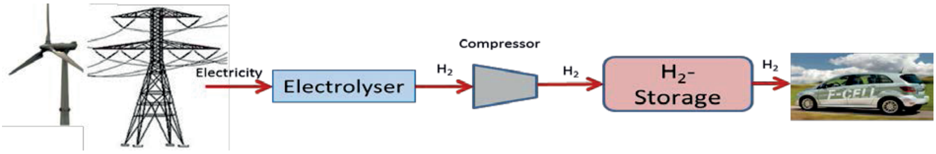

Fig. 6. Energy supply chains: Use of RES in FCVs

Since the transport sector, especially road transport, is one of the largest emitter of GHG emissions, it is very important to increase use of RES for mobility. According to the 2020 climate and energy package by 2020 share of energy consumption produced from renewable energy sources in the EU should increase for 20%. However, the options for the use of RES in transport are much more limited than in the heating or electricity sector. Currently, the mostly used alternative fuels are biofuels which have been increasingly criticized in recent years (Ajanovic, 2010; Ajanovic&Haas, 2010). In the last years huge effort has been put on an increasing penetration of electric vehicles. Unfortunately, there are still major technical and economic barriers, such as limited driving range and high investment costs, curtailing the broader use of battery electric cars (BEV). Hydrogen powered fuel cell vehicles (FCV) are another possible zero-emission automotive technology for the long term. However, BEV and FCV are really environmentally friendly only in combination with RES.

4. Conclusions

With increasing electricity generation from intermittent RES the need for storing electricity increases. At the same time the need for environmentally friendly technologies in the transport sector increases, too. In this context mostly discussed automotive technologies are BEV and FCV, as well as corresponding energy carriers, electricity and hydrogen.

Every considered energy carrier and automotive technology has some advantages and disadvantages. In opposite to BEV, which are mature technologies already available in the market, FCV are a long-term option mostly due to high costs and missing infrastructure.

Hydrogen could be used as a fuel for mobility but also as energy storage for volatile RES. However, very long energy supply chains are always connected with energy losses at the every conversion step. Energy chains with storage of RES via hydrogen and re-electrification are relatively inefficient. A better efficiency could be reached by the direct use of hydrogen in the transport sector without re-electrification. Due to very good energy efficiency of BEV and FCV, even in the case of the low efficiency in a well-to-tank (WTT) energy supply chains, total WTW efficiency could be competitive with conventional fuels and vehicles.

Since FCV are zero emissions vehicles (with better characteristics than that of BEV) political support for the market penetration of these vehicles can be expected. However, it is likely that the economic competiveness of these vehicles will be reached only beyond 2030.

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Energy and environmental impacts of an Italian Gypsy camp: a preliminary analysis

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Abstract

Slums represent a sort of black box within the urban environment, generating several impacts with respect to energy, the environment and the economy. On the other side, the dimension of social exclusion should be also accounted. These criticalities pose a further threat to urban sustainability. Data are needed to assess the environmental status of slums around the world in order to drastically change the quality of life both for their inhabitants and for areas surrounding those where they are located. A preliminary evaluation of environmental impact assessment was conducted, related to a specific Roma-populated slum in Naples (Southern Italy) for their relevance to the public health. In particular, an estimation of generated solid waste and wastewater amounts was performed; in addition, considering this type of slum time limited, costs for soil reclamation were calculated.

1. Introduction

The discussion about the nature of cities is still ongoing after several decades (Harris and Ullman, 1945). Whether they are ‘brains’ or ‘parasites’ still remains an open question (Liu et al., 2016). Nonetheless, in many cases the increased dependence on non- local sources, as well as non-renewables compared to renewables, are major drivers of the present pattern of urban unsustainability wordwide (Zucaro et al., 2015). Slums represent a special case of sub socio-ecological system within the urban environment. In particular, UN-HABITAT defines a slum[1] household as a group of individuals living under the same roof in an urban area who lack one or more of the following: Durable housing of a permanent nature that protects against extreme climate conditions; Sufficient living space which means not more than three people sharing the same room; Easy access to safe water in sufficient amounts at an affordable price; Access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people; Security of tenure that prevents forced evictions. Representing a case of evident inequality within the urban context, the first step toward remediation and improvement of their life quality is assessing their conditions, both with respect to the population (e.g.: health, education, and so on) and to the environment.

The metabolism and environmental impact of slums is seldom investigated, due to the difficulties in collecting the necessary data. Moreover, the main case studies reported in the literature refer to urban contexts with respect to developing countries. Instead, the purpose of this paper is to give a preliminary semi-quantitative evaluation of the energy and environmental impacts referred to the specific case of a Gypsy Camp in Italy. Gypsy camps have a symbiotic life with respect to the urban environment in which they are found. Moreover, they are often considered as parasites for the local population, since it is thought that obtain benefits from a ‘host’, which they usually injure

[1] http://mirror.unhabitat.org/documents/media_centre/sowcr2006/SOWCR%205.pdf

through the generation of a wide set of adverse impacts. Limiting the attention on the energy and environmental aspects, Is this fact true? If yes, how much does a Gypsy camp impact on the surrounding environment? If no, which are the benefits introduced by such settlements? Finally, which policy approaches could be envisioned to improve the detrimental effects of gypsy camps, if existing? The answer is possible integrating a metabolic and an environmental impact assessment.

2 Instruments and methods

First, as written before, a Gypsy camp, as a special example of slum in Europe, is a sub socio-ecological system, which takes its resources from the environment (acting as a symbiotic living being) and exerting an environmental impact on the same environment (acting, thus, as a potential parasite). The preliminary energy and environmental impact assessments, as well as a partial economic assessment of operating and remediation costs, are made on the base of a few data, since, as usual, quantitative information is missing for slums, particularly in the case of European ones. Population data, as well as economic costs, are derived from the last available report on gypsy camps in Italy, published in year 2013[2]. The basic voices of the input for the system (i.e.: gypsy camp) are: food (accounted in term of energy need); water consumption (cubic meters); additive energy (such as electric energy and anything that gives additive power to man (Sertorio and Renda, 2009)); input material (mainly derived from informal waste picking). Partially accountable outputs are waste and waste (sludge) water production. Economic costs are also defined, when possible. Data are taken from the available literature and official reports related to field surveys.

3 Results

The preliminary energy, waste and environmental partial Inputs, outputs, impacts and economic costs generated by a Gypsy camp are listed in Table 1. Literature data, to which the values are referred, are also shown. Atmospheric emission data are not available. Waste generated from waste picking activity is also missing. The amount of materials (kg/capita/day) collected from waste picking informal activity is listed, calculated as mean value of collected waste by waste pickers in different areas of the world.

The cost for site remediation is derived from a report (EP-NRA, 2008). The assumption is that the site should be considered as complex. In fact, at least three main conditions are respected, which reflect the complex nature of the brownfield after the eviction of a Gypsy camp: services may need to be cut off at the site boundary or from below ground (e.g.: illegal electricity and water connections); demolitions could be complex and risk of contamination might be present; hazardous materials and contaminants might be encountered. Depending on the foreseen end use, remediation costs are variable. Thus, a value range is determined (minimum and maximum costs). The camp from which the costs are derives is the one located in Secondigliano - Scampia, where the data (costs and population size – i.e.: 700 inhabitants – were available). The monetary costs, originally reported with respect to a range of years, are actualized

[2] http://www.lunaria.org/wp-content/uploads/2013/09/segregare.costa_.pdf

using the official Italian Statistical Institute (ISTAT) online calculator[3]. Potential remediation costs are derived considering the Gypsy camp located in the area of Brecce di Sant'Erasmo, where the size of the brownfield is known (i.e.: 82,034 m^2, equivalent to 8.2034 ha).

In order to make an approximate year esteem of waste picked by people living in a Gypsy camp, we have to make some preliminary assumptions. First, a report discussed in the Italian Senate contains an esteem about the population under 18 years of age, which should constitute about 60% of the Gypsy population in Italy[4]. Considering the sub-repartition of this category, it is also known that 46% of the total population is between 14 and 18 years. On the other side, the same report indicates that only 2.8% of the population is above 60 years. The same investigation reports that about 18% of the Gypsy population (also including the ones living in the camps) has a regular working activity (Basso, 2016). This means that about 20% of the population might be working in the 'informal' waste-picking activity. Referred to 700 inhabitants of the Scampia Gypsy camp, the esteem of collected waste along a year is, then, accounted for 140 inhabitants. Thus, the approximate total amount of collected becomes $1.75*10^6$ kg. On the other side, the produced waste (without accounting about the waste produced by informal activities) is $3.73*10^5$ kg (i.e.: $5.32*10^2$ kg/capita, against an Italian mean value of $4.88*10^2$ kg/capita[5]). The amount of wastewater produced (hydraulic charge) along a year is $8.18*10^4$ m^3, while total water demand by Scampia camp is esteemed around $1.02*10^5$ m^3.

An esteem of year economic costs – expressed in €, and reported for year 2017 -- are: 1,253,224.00 € (electric energy); 287504.00 € (water); 74,025.00 € (maintenance). This represents a total year cost of 1.614.753.00 € (i.e.: each camp inhabitant produces a cost for the urban community of € 2,306.79). The mean cost (independently from the final destination) for a camp remediation is of € 3,351,684.33 €. Finally, the approximate cost for waste management, derived from the mean Italian cost referred to year 2015 (i.e.: 38.56 €cent/kg), actualized to year 2017 for the total amount of waste generated along a year, becomes €144,547.94 (i.e.: a generated cost of 205.47 €/capita). If we add this cost to the total year cost shown before, the final year cost of Scampia Gypsy camp becomes € 1,758,581.80.

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[3] http://www.istat.it/it/prodotti/contenuti-interattivi/calcolatori/calcolo-delle-rivalutazioni

[4] http://www.senato.it/documenti/repository/commissioni/dirittiumani16/Rapporto%20conclusivo%20indagine%20rom,%20sinti%20e%20caminanti.pdf

[5] http://admin.isprambiente.gov.it/files/pubblicazioni/rapporti/RapportoRifiutiUrbani_Ed.2016n.252_Vers.Estratto.pdf

Table 1: Energy, waste and environmental preliminary Inputs, outputs, impacts and economic costs generated by a Gypsy camp

QUANTIFICATOR	UNIT MEASURE	VALUE	REFERENCE
		INPUTS	
Food energy (flow)	W/capita	$1.40*10^2$	Gorshkov (1995)
Electric energy	W/capita	$1.11*10^2$	Derived from electric energy costs for year 2013.
Additive power (flow)	W/capita	$3.99*10^2$	Casazza et al. (2016)
Total power consumption (flow)	W/capita	$5.00*10^2$	…
Water demand	m^3/capita/year	$1.46*10^2$	Derived from water cost in the years 2005-2011
Material input from individual waste picking	kg/capita/day	$3.42*10^1$	Mean value. Derived from Wilson et al. (2012)
		OUTPUTS (DAY)	
Waste production (mean solid waste generated)	kg/capita/day	$1.46*10^0$	Solid Urban Waste fraction, derived from ISPRA (2015).
Waste production (derived from waste picking)	kg/capita/day	NA	No literature or field survey data available
Fresh waste production (volume)	m^3/day	$9.73*10^0$	Derived from ISPRA (2015)
Compact waste production (volume)	m^3/day	$2.43*10^0$	Derived from ISPRA (2015)
Wastewater production (COD)	kg O_2/day	$4.20*10^1$	Derived from Metcalf & Eddy (2003)
Wastewater production (Hydraulic charge)	m^3/day	$2.24*10^2$	Derived from Metcalf & Eddy (2003)
Wastewater BOD_5	kg O_2/m^3	$1.88*10^{-1}$	Derived from Metcalf & Eddy (2003)
Emissions	NA	NA	No data available
		MANAGEMENT COSTS	
Electric energy	(€/capita) per year	1,790.32	Derived from BCLO (2013)
Water services	(€/capita) per year	410.72	Derived from BCLO (2013)
Maintenance (ordinary and extraordinary)	(€/capita) per year	105.75	Derived from BCLO (2013)
Removal of toxic wastes	€/capita (once)	140.71	Derived from BCLO (2013). The datum is of year 2008 and actualized to year 2017

Mean remediation cost	€ (approximate cost – corrected for current year)	3,315,401.04 = = = 3,474,758.20 = = = 3,315,401.04 = = = 3,301,177.04	Derived from EP-NRA (2008). The site is considered as complex. The costs are considered for different final destination use (from top to down): mixed use; residential use; mixed open space; employment

4 Conclusions

The results of this preliminary research, even if approximate due to the general lack of data, represent a contrasting scenario. In fact, the energy impact of a Gypsy community seems low with respect to the urban context. Moreover, the informal activity of waste picking, even if involving a small percentage of the community members, represents a special case of waste reuse, becoming a possible example of circular economy application into a real case study. On the other side, the environmental impact, as preliminarily assessed here, is high, as well as the economic costs, which are sustained by the urban communities which host the Gypsy camps. Consequently, Gypsy camps might well represent an interesting case of disentanglement between energy and environmental impacts. Further studies should be directed toward a deeper understanding and assessing of environmental impacts in order to take the appropriate counter-measures to reduce them.

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Advanced renewable polygeneration systems producing electricity, heat, cool and water: dynamic simulations and thermo-economic optimization

Francesco Calise

The overall world energy consumption is significantly increasing, mainly due to the economic development of emerging countries. The energy demand is mainly matched by fossil or non-renewable fuels, such as gas, oil, carbon, nuclear, whose availability and environmental impact are becoming a severe issue. Simultaneously, the consumption of fresh water is dramatically increasing, so that, according to several scientists, such resources will become even more crucial than energy [1]. In order to achieve a sustainable development, some significant actions must be taken, aiming at increasing energy efficiency levels, use of renewable and alternative sources and at reducing the environmental impact of energy-related technologies [2].

In this framework, one of the most attractive novel concepts is represented by the polygeneration. This technology consists in the simultaneous production of multiple energy vectors (electricity, heat, cooling) and other products (water, hydrogen, glycerin, etc.). In particular, polygeneration systems are very attractive when fed by renewable energy sources, since in this configuration energy efficiency and environmental compatibility are especially high. Despite their high potential, polygeneration systems are still scarcely used. In fact, on average, polygeneration only accounts for 10% of the global power generation. However, in some countries, such as Denmark, Finland and The Netherlands, this ratio may also increase up to 30%–50%. Currently, several countries are promoting the development of efficient and sustainable polygeneration systems: the European Union (EU) considers polygeneration as a strategic technology, in order to meet its target regarding the reduction of greenhouse gas emission. Similarly, USA is promoting polygeneration to cut down energy production costs in the industrial sector. Supporting mechanisms are also available in other countries worldwide [3].

As a consequence, academic institutions and industries are currently performing a significant research effort in order to develop efficient and economically viable polygeneration systems based on the utilization of both fossil and renewable energy sources. As for fossil fuels, researchers are performing several analyses aiming at optimizing cogeneration and trigeneration power plants. Conversely, researchers involved in renewable energy are developing different hybrid layouts where conventional technologies (internal combustion engines, Stirling, Rankine, gas turbines, etc.) are hybridized with renewable energy sources (especially solar and biomass) in a single efficient polygeneration system. In many cases, such polygeneration systems also provide other products, such as desalinated water, hydrogen, etc. [4]. Thus, polygeneration systems typically include a plurality of different technologies, integrated into a single system, so that the development of optimized control strategies becomes a crucial issue [5, 6]. A special design effort must be also made to determine the optimal size of each sub-component [7]; with this aim in mind, advanced analysis methods must be also used, such as exergy [8, 9], exergoeconomic and thermoeconomic analysis [10, 11].

Polygeneration also has a strategic role in the development of the distribute generation (DG). This is included in the more general concept of distributed energy systems (DES), which implies the integration of several small-scale DG technologies, instead of a limited number of big, remote power plants (centralized production). In DES systems, the electric energy is produced locally, avoiding transmission losses, promoting the concept of self-sufficiency and reducing the dependence on external energy supply. In DES systems, polygeneration powered by renewable energy is commonly considered the best candidate among the possible DG technologies. Such systems usually integrate district heating and cooling (DHC) networks, and off-grid generation islands which are connected by a private network [3].

As mentioned before, the number of possible polygeneration layouts is virtually infinite since it is possible to combine all the available fossil and renewable conversion technologies. Simultaneously, a plurality of different techniques can be used to analyze such systems. In this framework, this work aims at presenting a comprehensive overview of the available polygeneration systems, producing electricity, heat, cool and/or water, paying special attention to the dynamic simulation and the thermo-economic optimization of such systems. Obviously, the most common polygeneration layout is based on cogeneration and trigeneration systems [12]. The work will present several polygeneration systems integrating biomass-based conversion technologies. In particular, a hybrid system including a solar heating and cooling subsystem, where a reciprocating engine fed by vegetable will be analyzed [13]. The engine waste heat is used as a backup for space heating or to drive an absorption chiller for space cooling purposes. The system is dynamically simulated in TRNSYS (Transient System Simulation Tool) from both energy and economic points of view. The results show that the system may be profitable, especially in case of public financial support [13]. Other studies used polygeneration systems in order to produce a specific product, such as ethanol [14] or methanol [15, 16]. In many cases, biomass-based polygeneration systems use cheap biomass as fuels. In fact, the possibility to fuel such polygeneration systems by agricultural wastes is extremely promising [17, 18].

Then, the integration of polygeneration systems with solar collectors will be analyzed in detail. An example of those systems is represented by an existing trigeneration system which is hybridized with a solar field equipped with concentrating photovoltaic thermal (CPVT) collectors [19]. The system includes a gas turbine, CPVT collectors, absorption chillers, tanks and balance of the plant (BOP) devices. The system supplies electricity, heat and cooling to a lot of hospital buildings. The system is dynamically simulated and economical parameters are also evaluated. These systems are especially promising for centralized polygeneration technologies using district networks [20]. A plurality of solar-based polygeneration systems are analyzed, including: concentration and stationary solar thermal collectors, fuel cells, photovoltaic (PV) collectors, wind turbines, absorption chillers, etc. Such technologies are analyzed in different configurations. The results of the simulations show that the optimal configuration is obtained by adequately combining the renewable technologies used [20].

Finally, it also worth noting that polygeneration systems are becoming more and more attractive due to their capability to produce desalinated water along with electricity, heating and cooling. This is a very interesting configuration, especially for isolated communities where a single optimized system can be used to provide, simultaneously, all the energy vectors and potable water [1]. In fact, in such cases, the availability of fossil fuels (and the related power plants) or fresh water is extremely scarce, whereas they are often rich in renewable sources (solar, wind, biomass and in some cases geothermal) and in many cases are close to the sea [21].

Several simulation models will be discussed regarding polygeneration systems integrated with seawater desalination, such as an innovative solar heating and cooling system based on CPVT collectors hybridized with a multi effect distillation (MED) desalination unit which was powered by solar excess heat and by a biomass fired boiler [22]. A similar system is investigated for the island of Pantelleria, where the biomass heater was replaced by a geothermal well [21]. In both cases, the performance predicted through dynamic simulations, supported by appropriate economic models, is excellent. Alternative configurations are also presented where CPVT collectors are replaced by conventional parabolic solar collectors, coupled with geothermal wells. In this case, geothermal and solar energy are supplied to an organic Rankine cycle, producing electricity. The exhaust brine is subsequently used for both space heating and cooling purposes and to supply heat to a MED unit [23, 24].

For all the investigated polygeneration layout, special attention will be payed to the methods used to develop the analyses. In particular, the approach based on dynamic system simulation will be discussed in detail, presenting: energetic, exergetic and economic models. Results of these numerical studies are analyzed comparing energetic and economic parameters among the different configurations. For the majority of the proposed polygeneration systems, results of the energetic and economic optimizations will be also presented.

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Environmental resources, economy, regulations: a lack of Community-Based Adaptation for two Medieval monastic communities

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Abstract

Two case studies, referred to two medieval monastic communities, to show the lack of Community Based Adaptation (CBA) to difficult or changing environmental conditions. These, in turn, can be broadly referred as 'energy-related' factors, since both climate variability/change and food fall under this category. In fact, climate variability depends on solar radiation flux, while food represents the energy intake basilar for human survival. The case studies refer to the monastery of Bobbio (Piacenza, Emilia-Romagna, Italy) and Castelletto Cervo (Biella, Piedmont, Italy). The first case shows a lack of transformation of harsh regulations to the difficult environmental conditions of that time, which leaded to a revolt inside the monastery. On the other side, the decline of Castelletto Cervo Cluniac priory depended upon a bad management of economic resoruces in a time of environmental variability, which affected the agricultural yield and the life of many villages in the considered area.

1. Introduction

The present exponential growth of human activities, with a consequent ever increasing demand for resources. Humans are crossing the existing planetary boundaries, increasing the risk of destabilizing the existing safe space for humanity. This problem, anyway, is not only a recent one. Past societies also experienced this reality, which eventually determined their collapse. Among the causes of societal failure, an important role is played by the lack of Energy Return On Investment (EROI or, sometimes, EROEI) (e.g.: Hall et al., 2009; Tainter and Patzek, 2012). In fact, both individuals and complex societies require energy from food and other external energy sources to survive, reproduce and improve their well-being. Moreover, energy supports the adaptation to environmental changes or stressors. As discussed by Tainter (1988), adaptation is related to problem-solving, which, in turn, is generally dependent on structural modifications of societies, which is an energy-demanding process. This adaptation depends on resilience, which is defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change to still retain essentially the same function, structure, identity, and feedbacks". Resilience, at local level, depends on Community-Based Adaptation (CBA), which, in turn, depends upon skills, experience, local knowledge and networks to undertake locally appropriate activities that increase resilience and reduce vulnerability (Dodman and Mitlin, 2013).

Two historical case studies highlight the potential dynamics of lack of CBA. They refer to two different Italian Christian monastic communities in the Middle Age, investigating on the lack of interplay among three main aspects of any community life: the environmental conditions; their economy and regulations, which were defined as “monastic triangle” in a previous study (Alciati and Casazza, 2017). Even if monastic communities are somehow special for their intrinsic nature, they may be of interest for qualitative and quantitative researches due to the uniformity of lifestyle within a given community. Moreover, comparative studies along time might be possible, under defined circumstances, due to the long-time preservation of internal regulations, defining the management of a community and its daily life, which didn’t change significantly along the last 1,000 years. The special interests of the pre-industrial epoch are two. From one side, it allows a better knowledge about the regulating mechanism of a low-carbon community. On the other side, it allows to recognize the potential causes of failure of a lifestyle (the coenobitic Christian one) which is showed a great stability potential, since it has been developed since about 1,700 years, rooted on the concept of stabilitas, which parallels in many ways the concept of sustainability (…). Finally, the individuation of case studies, representing a lack of integration of components within a socio-ecological system on a local scale, can support better decision-making processes for the future.

2. Study methodology

2.1 Methodological approach

This work is based on a multi-disciplinary review and reanalysis of the existing literature, archaeological evidence and documents (i.e.: manuscripts), which can be referred to the life of the communities under study, the surrounding environmental and economic conditions and the evidence of community social conditions along the considered time periods. In particular, the literature search was performed through ‘Google Scholar’ search engine, searching existing works focused on climate, environment, economy and monastic communities, separately referred to the areas and time under study. The time search, performed excluding the citations, was conducted, first, looking to the last 5 years and, then, removing the temporal limitation of the outputs. Moreover, the main existing monographies were consulted to study the state-of-the-art about the history and archaeological data about the two monasteries. In the present version of this manuscript, several references will be omitted for sake of brevity. They will be reported in the future full version of the same work.

2.2 Case studies

The first case study refers to the monastery of St. Columban in Bobbio (High Trebbia valley, Piacenza, Italy). This study considers the period after the death of St. Columban, occurred in year 615 AD. The interest is focused on the potential causes of a revolt against the Abbot, Attala, after the death of the founder of the community. The second case refers to the Cluniac priory of Castelletto Cervo (Biella, Piedmont, NW Italy) in the time range from the XII century AD to the XV century AD. The reason of interest is its economic decline, until its suppression. Figure 1a and Figure 1b indicate the location of the two monastic communities.

These two case studies attracted our attention for different reasons. With respect to the first one, the main work investigating the causes of the occurred revolt hypothesizes the lack of charisma of Abbot Attala in managing the revolt, originated by the harshness of the monastic rules applied to the community (Dunn, 2008). Nonetheless, these regulations were chosen freely by the same monks, who were responsible for the revolt. Moreover, the decision of leaving a monastery was generally heavily punished. The second case, instead, refers to a smaller community, a Cluniac priory, whose decline was caused by a bad management of economic resources (Destefanis, 2015). It is, however, amazing how these critical conditions occurred within just three years. In addition, despite the documented improvements in management, as periodically reported by the available sources, the monastery's fate didn’t change at all. With respect to both cases, the reduced availability of documental sources, while limiting the presence of direct witnesses, stimulated the investigation on the local ‘boundary conditions’, which now potentially suggest a different narrative of the facts.

3. Results and discussion

3.1 Bobbio and the revolt against Abbot Attala

Around the year 614 AD, the Lombards' sovereign, Agilulf, granted Columbanus a licentia habitandi ac possidendi in Bobbio (Piacenza, Italy), on the site the old church of St Peter, the centre of the future monastery. The monastery of Bobbio is located close to the river Bobbio, a tributary of the river Trebbia, in a mountainous area of the Emiliano-Ligure Apennines. In year 615 AD, the great Irish monastic leader, Columbanus, died in Italy at his monastery and, after his death, Attala took his place as the Abbot of Bobbio. Only sixteen of the monks are known today over the 24 years described by Jonas of Bobbio (Jonas of Bobbio, 2000), a monk who lived there at the time of the events. In any case, the size of the original community is still unknown. Attala “was ruling the aforesaid monastery with distinction in succession to the blessed Columbanus and was guiding it in every discipline consonant with the tenor of a monastic rule […]”. When Attala took the place of Columbanus, “[…] the subtlety of the old serpent began to spread the fatal virus of discord with injurious blows, exciting the hearts of some of his subordinates against him so that they claimed that they could not bear the precepts of excessive ardour and that they were unable to sustain the weight of harsh discipline […]”.

First, it is important to consider the potential harshness of the rule, which is witnessed by Jonas. We have two Rules[1], which are attributed to St. Columbanus: the 'Regula Monachorum' and the 'Regula Coenobialis'. The first and earlier one was probably written during his staying at Luxeuil (591/593–610), while the second was written later. An important question arises about the signs of harshness of a rule (or, better, of its application), since it is obvious, as it was at that time, that the monastic choice was hard and acceptance within a community wasn't, in fact, immediate. Such signs shouldn't be either poverty or prayer or obedience or silence, which are mentioned and common in the monastic rules and lifestyle. Thus, the only real signs could be related to the daily work or food. Both of the rules, in fact, report strict regulations and heavy

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[1] The 'Regula Monachorum' text can be found trough the 'Biblioteca Augustana' at the web address: http://www.hs-augsburg.de/%7Eharsch/Chronologia/Lspost06/Columbanus/col_intr.html, while both the 'Regula Monachorum' and 'Regula Coenobialis' can be found at http://ora-et-labora.net/regulacolumbani.html as contained in George Stuart Murdoch Walker ed., Sancti Columbani Opera, (Dublin: The Dublin Institute for Advanced Studies Dublin, 1970), as digitalized by 'Corpus of Electronic Text Edition' - http://www.ucc.ie/celt.

punishment against who doesn't follow the rule. The specifc points are not reported here for sake of brevity. They will be considered, instead, in an extended version of the present paper, which is under preparation. The application of the rule certainly supports Jonas' explanation about the cause of the revolt. Nonetheless, this would be partially insufficient, since the rule develops in a context, a matrix from which the rule was originated and grew. The rule (i.e.: a set of regulations both for reaching a spiritual perfection and for managing the survival of a community) was usually learnt and accepted by the monks before stably entering into a community. Furthermore, the revolt didn't occur centuries after the death of St. Columbanus, but when part of the original community involved in the foundation of the monastery was still alive and present.

The initial core of the monastic property covered a surface area of about 4 miles. A simple calculation can be made30 knowing the approximate productivity for wheat and durum, used as sample crops, and knowing the mean metabolic need for an adult, which is $1.4*10^2$ W (Casazza, 2012). Let us consider the wheat caloric content ($1.69*10^7$ J/kg), an average mean wheat productivity with reference to 2,000 years ago of 1.5-2 t/ha, and the 1-year cycle as a time reference (1 harvest per year for wheat) (Jacobsen and Adam, 1958). The same calculation can be made for durum (Buonincontri et al., 2014), whose caloric content is $1.47*10^7$ J/kg, while its mean productivity during the same period was 0.10-0.5 t/ha.34 It is known that an adult male requires a mean daily food energetic intake of 2,200 kcal (Doughty and Field, 2010; Zadoks, 2013). With respect to the size of the community, research has shown that the size of many communities ranged between 12 and 20 monks, while an important community would have 40 monks and those with 50 or 60 monks were exceptional. Thus, considering an exceptional size (this is done conservatively), the community size could be up to 50 people. When founded, the monastery of Bobbio had an available surface area of 4 miles (i.e., about $2.8*10^7$ m^2). The energetic (metabolic) need for feeding the monks in 1 year was $1.68*10^{11}$ J (this number is obtained by multiplying the energetic need of 1 man for 1 year for the number of inhabitants of the monastery). Considering the available data, it is possible to determine that a surface area of $7.44*10^4$ m^2 would have been necessary, in the case of wheat cultivation (0.26% of the available surface area) or $7.44*10^4$ m^2 would have been necessary, in the case of durum cultivation (3.17% of the available surface area) for feeding the monks of Bobbio. An additional surface area would have also been necessary for cultivating cereals, necessary for producing the beer which was usually consumed, according to Jonas' writings and to the rule of St. Columbanus. This means that, theoretically, the available surface area was sufficient for starving the monks.

Nonetheless, looking at the characteristics of the Bobbio area, it is possible to find ophiolites (i.e., an igneous rock consisting largely of serpentine) in the soil, while we must also note the presence of salt nearby, due to the availability of salty water (Scelsi and Gattinoni, 2009). These facts represent a strong partial limitation to the fertility of the area. Furthermore, some of the resources were shared with other people, such as is the case of the well for extracting salt, since it was owned by Sundarit (the availability of salt was of paramount importance for preserving food). The conditions of abandonment of the territory, as described by Jonas, when St. Columbanus arrived with his community about one year before his death, also constitute a limitation for the survival of the community. The archaeo-botanical data from northern Italy already show an agricultural world in crisis in urban and rural sites38. Moreover, starting from the 4th century AD, the fluvial system was in a metastable equilibrium, while the alluvial fans had the tendency to aggrade, mainly as a concurrent consequence of bad climatic conditions and as a sign of the loss of the land preservation systems in the mountain catchment areas. The fact is confirmed also by the extrapolation of the Po River discharge before 1917 to the last 2 millennia, which indicates a period of high discharge also around and shortly after 600 AD. A significant sign of change in climatic conditions in the period of transition between the Late Roman Empire and the early Middle Ages is the reversion from arable to pasture lands, which affected regions as far apart as Italy and Poland and cannot be ascribed merely to the political and fiscal dislocation of the ancient world, but should be understood as one effect of the climatic anomaly. Meanwhile, several volcanic eruptions further affected the climatic conditions. The sum of these and other concurring effects, evidenced also by new paleoclimate data, has now supported identification of the interval from 536 to about 660 AD as the Late Antique Little Ice Age (LALIA). The LALIA could have played an important role in the availability of energy resources, considering both food and primary energy sources, thus affecting the EROI for the community. In any event, this factor merits further investigation (Büntgen et al., 2016).

Consequently, the new framework, which can be obtained by combining the written testimony of Jonas and the scientific literature, indicates that the community of the Bobbio monastery initially had to deal with strong environmental stressors with respect to landscape degradation due to its partial abandonment and to the geological characteristics of the soil, which were not favorable for the development of agriculture. Furthermore, the adverse climatic conditions, characterized by some cold and wet periods now recognized as the LALIA, worsened the living conditions of the community, which should have adopted a different strategy with respect to the application of the Rule, thus improving CBA with regard to the previously mentioned adverse factors.

3.2 The Cluniac priory of Castelletto Cervo and its decline

The presence of the Cluniac monks in the locality of Castelletto Cervo (diocese of Vercelli, NW Italy) on the hill, once called Castelletto Monastero, is recorded from the end of the XI century. In year 1083, the local nobleman, Count Guido II of Pombia, donated to Cluny a church, about twenty mansions in Valsesia, two large pastures at the foot of Mount Rosa with herds of cows and bulls and four important forests on the same mountains. The priory, built on 1095, was erected on the hilltop of Castelletto Cervo, as a support point of transhumance practice in cattle breeding. Just in the hillsides of Castelletto and the nearby Greggio, where the so called “baragge” (i.e.: moors) can be found, the monastic herds were wintering, moving toward the wide mountains of the Sesia valley, under the glaciers of Mount Rosa. In year 1184, Pope Lucius III could confirm, after having received the priory under his apostolic protection, the total property of three villages, mountain pastures and mountain forests, an unspecified number of mansions in 12 locations, and 24 churches in the dioceses of Vercelli and Novara. The majority of archival documents were lost in the past. Consequently, the available news is few. The original sources report an initial economical criticality between 1280 and 1286, apart from some prior litigations, related to the use or property of some of the land assets. The financial and material collapse of the structure was recorded until year 1306. After a resumption of year 1310, the community moved to the granary of Carpignano, since in 1331 no-one dared to stay in

Castelletto because of the wars. Only in 1342 the community returned to its original location. The economic conditions of the community improved between 1366 and 1369, but returned to be critical between years 1372 and 1378. The community faced a slow decline, reported by historical events recorded from available documents, which also include a gradual usurpation of the movable and immovable properties of the monastery.

This crisis was not limited to the priory, but to all the territory under the diocese of Vercelli, where numerous cases of temporary and definitive abandonment of villages occurred, and behind it. Both the plague of the mid-13th century and the war, which only temporarily aggravated the situation, were not the main cause of this status. Instead, compared to the 13th century, a strong perception of depopulation already existed. Many witnesses reported also the great difficulties of large owners to find farmers willing to cultivate their funds (Rao 2011, pp. 45-46). A geographical and temporal coincidence between the original provenience of these documents and the abandoned villages is found. Large-land owners were forced to reforest the most disadvantaged funds because the arable fields were left or for a precise decision local people. These difficulties were in close correlation with poor yields and the reluctance of peasants, who lived in widely available territories, to hire leased funds, except under very advantageous contractual terms. From an economic perspective, two economic factors contributed to the findings: the labor productivity, especially since the 14th century, and the loss of yield of the most fertile soils. The latter condition depended upon climatic conditions. Starting from the 14th century, the transition between the MCA and the LIA is observed. During this period of strong environmental instabilities, proxy data show both the number increase of cold winters and, on the other, two periods of long (multi-year) tendency to drought. The situation was further exacerbated by the effects of frequent volcanic eruptions, which, by reducing the incidence of solar radiation on the Earth's surface, not only influenced the surface temperatures by lowering them, but also reduced the agricultural yield. Finally, the hydrological data derived from the proxies confirm a gradual deterioration of the Po river by the 15th century.

3.2 Discussion

First, a methodological remark. the two case studies of our research deal with a reduction of energy-related resources at local level. In fact, climate variability is mainly an alteration of Earth energy cycle induced by a variation of solar flux income. This change was also forced by volcanic eruptions. The consequence of reduced agricultural yield is also an energy-related factor, since it represents the energy intake (i.e.: food) for humans. The hidden presence of energy causes in the development of critical conditions for community survival is a leitmotiv of our examples. Nonetheless, this fact is not straightforward, while it requires an analysis of existing boundary conditions. This fact parallels the social impact of environmental harm, where causality nexuses are extremely difficult to reconstruct.

The lack of CBA is reflected in the two case studies, where the environment-economy-regulation triangle was broken. In particular, the examples show an intrinsic inertia of the system toward a change of habit, that is reflected into a worsening of social conditions, derived from the chosen lifestyle options. The integration of historical sources, archaeological finds and literature review show again that the social and the ecological dimensions cannot be considered separately. Rather, they are mutually influenced and inter-related. The case of Bobbio illustrates a weak community adaptation between environment and regulations, while the second one describes an extended weak adaptation between economy and the environment. This doesn't mean that no feedback exists. Instead, the outcome of the weak adaptation consists in the choice of wrong social options. In the first case, this 'mistake' is represented by the strict preservation of the rule, without any adaptation. In the latter one, apart from the possible individual responsibilities within the community, the 'mistake' are related to the preservation of taxation levels, which impoverished the community, and the absence of variation in the productive activities of the community. In fact, cattle breeding and ceramic production remained the main source of income for the priory, disregarding the changing surrounding conditions.

Some considerations are also necessary to plan a positive transition toward low-carbon societies, as foreseen by many international policies. The role of local governments will be pivotal in this societal transformation. It will be important for the future to achieve a greater integration between ecological concepts and governance. As describe in the same research, this will require a multi-disciplinary approach, stemming from four actions: a qualitative characterization of extant range of ecosystem services and potential regime shifts; the development of models for adaptive governance; the definition of administrative laws, that facilitate development of networks and the response alignment the scale of considered social-ecological changes; an implementation of such model on the basis of existing legal foundations. The cultural dimension of CBA was excluded from the present study. Nonetheless, being recognized as an important factor for adaptation to climate and environmental change, this will require further investigation. We have to remark that also the role of traditional knowledge should be included, in order to see, in our case, the potential influence of traditional monastic culture behind the monasteries' walls. In fact, traditional knowledge/wisdom is increasingly recognized as valuable for this purpose. Another dimension which might indirectly affect also the life of local communities and which was obviously excluded from this study, is finance, which didn't exist at that time.

4. Conclusions

This paper demonstrates the importance of CBA with respect to the integration of environmental, economic and regulatory factors. This is particularly important for two main reasons: (1) the present state of resources over-exploitation; (2) the present increasing risk of resources availability. In particular, if no integration is performed within a community among the considered aspects, there might be an increasing risk for communities' stability. On the other side, the historical perspective is useful to demonstrate how CBA will be important in the transition toward low-carbon societal lifestyles. This work evidences the importance of laws and regulation, as well as economy, to ensure the proper interaction between humans and the environment, thus stressing the importance of a different approach to regulatory and policy-making processes, also in the present, within the framework of the necessary transition to a more sustainable lifestyle.
Finally, the study of socio-ecological systems at community level, which includes also the analysis about CBA, have gained further importance under the light of the newly reached agreement during Paris climate conference in December 2015. In fact, since

the studies on human adaptation to planetary boundaries are scarcely developed at a local community level, some new insights can be surely obtained thanks to the study of the past.

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Energy efficiency in the residential sector: identification of promising policy instruments and private initiatives among selected European countries

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Abstract

Improving residential energy efficiency is widely recognized as one of the best strategies for reducing energy demand, combating climate change and increasing security of energy supply. However, progress has been slow to date due to a number of market and behavioural barriers that have not been adequately addressed by energy efficiency policies and programmes. This study is based on updated findings of the European Futures for Energy Efficiency Project that responds to the EU Horizon 2020 Work Programme 2014-15 theme 'Secure, clean and efficient energy'. This article draws on five case studies from selected European countries - Finland, Italy, Hungary, Spain, and the UK - and evaluates recent energy efficiency developments in terms of indicators, private initiatives, and policy measures in the residential sector. Our analysis shows that the UK government has implemented a better range of policies, coupled with initiatives from the private sector, aimed at improving energy efficiency. However, its existing conditions appear to be more problematic than the other countries. On the other hand, the lack of effective and targeted policies in Finland resulted in increased energy consumption, while in Hungary, Spain and Italy some interesting initiatives, especially in terms of financial and fiscal incentives, have been found.

1. Introduction

Energy efficiency is widely considered as the most cost effective way to enhance security of energy supply, and to reduce emissions of greenhouse gases. In fact, the cheapest energy, the cleanest energy, the most secure energy is the energy that is not consumed at all (EC 2016a). Furthermore, energy efficiency improvements might have the potential to support economic growth and social development, to improve occupant health and well-being, and to enhance competitiveness and investment opportunities (IEA 2014a).

In the last years, the European Commission has acknowledged these benefits in a series of directives and long-term strategy documents - such as the Energy Performance of Buildings Directive 2010/31/EU, the Energy Efficiency Directive 2012/27/EU, the Energy Roadmap 2050, etc. - by establishing a set of measures for improving the existing policy framework of measures and promoting energy efficiency within EU. In addition, the new 30% binding energy efficiency target for 2030 recently proposed by the European Commission in the Winter package (EC 2016a) put the level of ambition of European energy efficiency policies into sharp focus. These regulations and policy documents have been mainly designed to meet the EU climate policy goals, i.e. an 80% reduction of CO2 emissions by 2050, but they are still not in line with the commitments under the Paris climate treaty which would require more efforts, so for the future stricter rather than relaxed regulations can be expected.

The residential sector is responsible for one of the largest share of energy consumption presenting the highest cost-efficient potential for mitigation, and it is consequently vital to meeting the EU objectives toward a low-carbon economy and energy system. Nevertheless, the move towards energy efficiency is happening too slowly and there continues to be a degree of inertia on a national level. Recent years' experience has shown that there are considerable barriers to full uptake of economically effective and technically feasible energy savings opportunities across the EU (EC 2016b).

In compliance with the Energy end-use efficiency and energy services Directive 2006/32/EC (ESD) and Energy Efficiency Directive 2012/27/EU (EED), Member States are required to translate the energy savings objectives into domestic and effective measures in their National Energy Efficiency Action Plans (NEEAPs). But there exists a wide disparity in terms of content, level of detail in describing, and the level of ambition about the energy efficiency instruments in place and planned for the next years between Member States. At the same time, the energy share of residential sector strongly varies among countries due to different energy infrastructure, climate conditions, energy resource availability, income, economic structure (IEA 2014b), dwelling characteristics, energy culture (Stephenson et al. 2010), household behaviour (Lopes et al. 2012; Frederiks et al. 2015), and other country-specific conditions.

Therefore, the type of policy instrument suitable for driving energy efficiency depends on many country and sector specifics, and the circumstances determine which policy instruments are more appropriate than others, depending e.g. on market and behavioural barriers, and target groups. However, the achievable impact of energy efficiency policies depends more on the design of the instrument and the way in which it is implemented than on the type of instrument itself (Phylipsen 2010).

Although policy maker have a major role to play in impacting energy consumption in the residential sector, there are many other players that can stimulate energy efficiency improvements:

- Energy Service Companies (ESCOs), under an Energy Performance Contracting (EPC) arrangement, implement an energy efficiency project and use the stream of income from the cost savings to repay the costs of the project;
- Energy utilities provide advice and assistance to energy consumers, technology development, on-bill financing, etc.;
- Non-Governmental Organisations (NGOs) promote energy efficiency through an active participation of citizens and provide input to policies;
- National or regional banks develop specific packages for households to support energy efficiency improvements, renewable energy and broader green investments.

A comprehensive review of all energy efficiency policies and private initiatives in the residential sector of the European Union is beyond the scope of this paper, but several instruments seem particularly relevant to understanding the recent trends of energy efficiency, especially in terms of country-specific actions. This paper provides some overarching European data and insights, but mainly concentrates on five case countries - Finland, Hungary, Italy, Spain and the United Kingdom - by evaluating recent residential energy efficiency policies and private initiatives complementing public activities.

In order to make a robust assessment and provide an accurate picture of the European Union and the countries under investigation, we first build disaggregated indicators of energy efficiency suggested by the International Energy Agency (IEA 2014b; IEA 2014c). By doing so, we provide a strong basis for policy making evaluation and development of effective energy efficiency strategies. Then, we assess the residential energy efficiency policies in force, identifying best practice, instrument-specific success factors, and policy gaps. Moreover, we analyse the role of the private sector in stimulating the investments in energy efficiency and complementing European and national public policies. We conclude by discussing whether the policy instruments and private measures targeting energy efficiency in the residential sector are sufficient to contribute to reductions in energy use. In addition, we formulate policy recommendations in order to strengthen the existing policy packages.

Most of the literature focuses on the analysis of the energy efficiency policies by the type of instrument (regulatory, economic, informational, etc.) without considering (i) the way they are implemented, (ii) synergies among policies, and (iii) the underlying determinants driving the design of a specific policy. In addition, to the best of the authors' knowledge, the role of the private sector across multiple actors in supporting the national government to stimulate energy efficiency investment in the residential sector has not been previously analysed.

2. The EU residential energy sector

For each energy end-use of the residential sector, we selected the indicators of energy efficiency suggested by the International Energy Agency (IEA 2014b; IEA 2014c), namely the final residential energy consumption per stock of dwelling permanently occupied (at normal climate), the final residential space heating consumption per floor area 1990-2014 (at normal climate), and the final water heating, cooking, electrical appliances and lighting consumption per stock of dwelling permanently occupied. While these detailed indicators do not fully explain what is driving the changes in observed energy consumption, they provide indications about recent trends, and combined with implemented European and national policy and private instruments aimed at reducing energy consumption and CO2 emissions, they can provide some guidance on the efficiency improvements achieved in the residential sector.

3. Promising policy instruments

As a requirement of the ESD and EED implementation, Member States had to develop and submit National Energy Efficiency Action Plans (NEEAPs) to the European Commission on a periodic basis, in which they estimate energy consumption, and report on the planned energy efficiency measures and the expected improvements in terms of energy efficiency. The introduction of the NEEAP reporting requirement encouraged Member States to think up new policies and measures to meet the energy savings targets. They are intended to stimulate the translation of energy savings objectives into concrete measures and actions, set implementation milestones at Member State level, and create dialogue between the Commission and Member States (EC 2009b). Thus, in the following paragraphs we provide in-depth analysis of the energy efficiency policies that have been recently implemented in the residential sector of Finland, Hungary, Italy, Spain and the UK, based on the barrier and/or specific target addressed.

3.1 Improving the energy performance standards of new and existing buildings

Buildings standards ensure that the desirable energy performance of e.g. building components and (especially) heating equipment is achieved even when its purchaser does not show interest in obtaining more efficient products due to either credit constraints or lack of incentives (IEA 2011). Reviews of the literature on energy efficiency policy shows that instruments such as energy efficiency standards have been one of the main drivers of innovation (Noailly 2012), and the preferred policy option in the European Union to address barriers to energy efficiency (Bleischwitz et al. 2009).

3.2 Financial facilities to encourage private capital investments

Financial incentives can take many forms – grants, subsidies, soft loan, etc. – and are commonly used to encourage energy efficiency improvements by lowering inhibitive up-front costs faced by households. According to the EED (preamble (52) and article 12 (2a)), Member States should make use, promote and facilitate innovative financing mechanisms that reduce the risks of energy efficiency projects and allow for cost-effective renovations among households. In Hungary, the main financial instrument managed by the central government to promote investments aimed at furthering energy efficiency in households is a grant scheme called the 'Warmth of the Home Programme'. In Spain, the Royal Decree 233/2013 of 5 April 2013 of the Ministry of Development approved the State Housing Plan aimed at promoting the energy renovation of residential buildings. The main functions of the State Plan 2013-2016 were underlined in its preamble: "to adapt the aid system to the current social needs and to the scarcity of resources available, concentrating them on two issues: the promotion of tenancy and the promotion of rehabilitation and urban regeneration and renewal."

3.3 Fiscal incentives that indirectly reduce the cost of investments

Fiscal incentives for the energy efficiency in buildings include several measures to lower the taxes paid by consumers and are one of the instruments that can be used by Member States to promote and facilitate efficient use of energy among domestic costumers (EED, article 12 (2a)). In particular, measures include tax deductions on retrofitting investments and equipment, tax credits, tax reductions and rebates, accelerated depreciation allowances, tax or customs duty exemptions. They are widely used across the European Member States but not to the extent of financial instruments as grants. From a government perspective, fiscal incentives impact revenues, while grants require outlay of the public budget. Fiscal incentives are difficult to limit to a certain amount of revenue forgone and the amounts may only come to light at the end of the fiscal year, while costs for grants may be easier to track and control as they have a certain budget limit (Hilke and Ryan 2012). However, one advantage of fiscal incentives over grants, is that they are more likely to encourage greater scale of projects as they are usually granted over a longer time period and do not have a limited budget attached (Dyer et al. 2011). Fiscal incentives have been traditionally common in Italy and Finland.

3.4 Promotion of small-scale renewable energy production systems

Most government policies start from the assumption that renewable energy and energy efficiency investments go hand in hand by creating a virtuous circle: one enhances the other. With greater energy efficiency, the total demand for energy drops, meaning that the same amount of renewable energy covers a larger share of demand. At the same time, renewable energy technologies enhance efficiency, creating a symbiotic relationship (IRENA 2015). In addition, many applications of renewable energy, in particular renewable heating technologies, are more effective in an energy efficient home. Thus, the Italian and the UK governments implemented policies to promote the generation of renewable thermal energy in buildings as a way of contributing to the national energy efficiency target.

3.5 Measures addressing vulnerable consumers and fuel poverty

The EED article 7 (7a) allows Member States to include requirements with social aims in their Energy Efficiency Obligation Schemes , as for example to prioritize households in energy poverty or social housing (EC 2012). However, most of the Member States have not translated this requirement into national legislation, if not through one-off measures. The United Kingdom is one of the few EU Member States where this problem is both recognized and systematically addressed by means of household support policies and energy efficiency investments (Bouzarovski 2014).

3.6 Measures addressing the landlord-tenant problem

According to the article 19 of the EED, Member States should take appropriate measures to overcome misaligned incentives between landlords and tenants. The landlord-tenant problem occurs when landlords have little incentive to invest in the energy efficiency of their properties, given that it is the tenant who benefits from lower energy bills (Allcott and Greenstone 2012). As a consequence, rental properties tend to be less energy efficient than owner occupied houses. This split incentive between owners and renters is one of the greatest barriers hindering the development of sustainable renovation of residential buildings in Europe, but it has hardly been an objective of policy-making. In 2015, on average in the European Union, 69.5% of the dwellings were owner-occupied (own it outright and mortgagors), while the remaining were privately or social rented. Significant differences exist among Member States: for example, in Hungary 86.3% of the dwellings, while in UK only 63.5%, were owner occupied in 2015.

3.7 Increasing consumer information and promoting behavioural change

Consumers need relevant information and motivation for taking action, and to be able to make informed decisions and choices towards energy efficiency measures. While information is not sufficient to generate motivation or change behaviour, it is nonetheless a necessary (but not sufficient) condition for action. The challenge is to provide the right information when decisions and choices are made, in a format that the citizens find interesting, useful and trustworthy. Information and educational programs typically aim to induce change of the consumer’s behaviour by providing information about potential energy savings from energy efficient products or investments and by including programs to give feedback to consumers about their energy consumption. The intention is that through the provision of greater and more reliable information, issues of uncertain future returns and asymmetric information may be lessened (Gillingham et al. 2009).

4. Private initiatives

Beyond public programs and policy instruments, energy efficiency improvements in the residential sector are supported by the private sector in a variety of ways:

- Initiating and implementing concrete actions, e.g. through providing loans, investment and implementing demonstration programs, alternative solutions to low-energy buildings;
- Organizing awareness raising and information exchange programs;
- Providing input to policies, analysing policies and initiating discussion.

4.1 Energy service companies (ESCOs)

The ESCO can be a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises - such as project finance, engineering, project management, equipment maintenance, monitoring and evaluation - and accepts some degree of financial risk in so doing (EC 2006). Despite the large economic energy saving potential, the ESCO market in the residential sector is much less developed compared to the industry, tertiary and public sectors in the European Union, as indicated in a recent JRC ESCO report (Bertoldi et al. 2014). Irrek et al. (2013) have traced the barriers preventing a large scale application of the ESCO concept in the residential sector on several sources: (i) the particularly high transaction costs for ESCOs relative to the small amount of energy costs and thus potential cost savings per single energy efficiency service supplied; (ii) the decision making processes existing in multi-apartment buildings, where typically at least one half of the apartment owners must agree on the energy efficiency investment; (iii) the perception of the ESCO as not a trustworthy organisation and the fear of households to become too much dependent on the ESCO, especially if the contract also includes the supply of energy; (iv) the difficulties for residential customers to understand the ESCO model and the EPC financing and contract and lack of information on the availability of ESCO services. The number of ESCOs, their market size and the type of services provided varies a lot among Member States. In Italy (that ranks second in terms of number of ESCOs in Europe after Germany) there were about 50-100 ESCOs in 2013, with a market size of €500 million.

4.2 Energy providers

The principal driver of the energy providers to deliver energy saving activities is induced by regulatory mechanisms created by the 'Energy Efficiency Obligation Scheme' (EEOS, article 7, EED) which calls on each Member State to ensure that energy providers achieve new savings each year from 1 January 2014 to 31 December 2020 of 1.5% of the annual energy sales to final customers of all energy distributors. In the transposition of the EEOS into national law, the government of Finland decided to adopt the 'alternative approach', meaning that it opted to take other policy measures such as energy or CO2 taxes, financing schemes and fiscal incentives, voluntary agreements, etc., in order to achieve an equivalent energy saving target, while Hungary, Italy, Spain and the UK adopted a combination of both EEOS and alternative measures (Bertoldi et al. 2015). Even though in almost all jurisdictions we find energy providers active in some form of demand-side management or other types of programmes, this energy efficiency activity seems to be only a window dressing or driven by legal requirements. On the other hand, in some cases energy suppliers seem to be genuinely attempting to develop and implement new business models that incorporate energy efficiency, driven by a non-traditional profit motive and a belief that it is the right thing to do (Fawkes 2016).

5. Conclusion and implications for energy policy

This study builds on the EU Horizon 2020 project 'European Futures for Energy Efficiency' and provides unique insights from a large set of different perspectives bringing out ground-breaking elements for the European residential energy sector. In this article we evaluated recent energy efficiency developments in terms of indicators, private initiatives and policies implemented in the residential sector over the last years in Finland, Hungary, Italy, Spain and the UK. Since it is not possible to show a causal relation between energy efficiency trends and differences on the basis of indicators alone, an assessment of implemented policies combined with private measures targeting energy efficiency in the residential sector can further improve the understanding of the country-specific conditions and actions. With the development of this framework that takes into account multiple actors and both quantitative and qualitative criteria in the evaluation process, we aim at contributing to a comprehensive and comparable analysis among case studies.

When compared to what has been done in the last years in Finland, Spain, Italy, and Hungary, the UK government seems to have implemented a better balanced set of energy efficiency policies targeted at the residential sector, with the participation of diverse private actors. In fact, a holistic policy package with a medium-term framework addressing many aspects of energy efficiency in the residential sector is also partially supported by a developed ESCO market and legal obligations placed on energy suppliers to deliver domestic energy efficiency programmes. But the UK residential energy sector appears to be more problematic than other countries. In particular, the prevalence of older dwellings in the national stock built to lower standards of energy efficiency combined with a high share of the private rented sector in the housing market leaves larger untapped potential for improvements than the other countries under investigation. In addition, a confusing number of only slightly different policy measures specifically address the same target (e.g. vulnerable consumers, energy poverty); increased flexibility, combined with a long-term perspective and continuous funding could help to optimise their impact.

With regard to Finland, improvements of energy efficiency in the residential sector seem not to be a priority for policymakers. Considering that Finland has one of the highest energy consumption per capita and space heating demand per dwelling in Europe, this result is quite surprising. Beyond a general tax reduction for any household services, no real economic incentives have been provided to stimulate energy efficiency investments in the last years. Also, issues like fuel poverty and the landlord-tenant problem have not been taken into account in the national energy efficiency strategy, and the private sector remains a marginal player. As a result, Finland is the only country that did not decrease its residential energy consumption per stock of dwelling permanently occupied within the period 1995-2014.

Also in Spain the residential energy sector seems not to be at the top of the political agenda, while a major attention has been given to the transport sector representing about 40% of the energy consumption. But as opposed to Finland and the UK, in Spain the residential energy sector is one of the most efficient in Europe, mainly because of the modern building stock and the low level of space heating demand. In addition, with the State Housing Plan 2013-2016 and the PAREER-CRECE Programme, both the national and local governments have recently allocated a significant share of the budget for energy efficiency and saving projects in residential buildings.

Similarly, with the Warmth of the Home Programme, the Hungarian government provided financial incentives to households ranging from the replacement of inefficient appliances or obsolete facade doors and windows, to complex energetic refurbishment of blocks of flats. The success of this policy measure has been witnessed by the rapid end of funds allocated (the other side of the coin is that the program was underfunded as compared to demand). Also, in order to increase energy awareness, large-scale educational programmes targeted to specific groups, have been provided by both the government (ECARAP) and the energy providers E.ON and ELMÜ-ÉMÁSZ.

With regard to Italy, we have found some interesting policy initiatives, especially in terms of fiscal incentives and promotion of small-scale renewable energy sources that have kept the energy demand per dwelling stable. However, these measures have not been developed into a comprehensive policy package addressing all the aspects of the residential energy sector. The tax deduction scheme (implemented for the first time in 2007 and still in force) has proven to be very effective in attracting more investments than what it actually cost in terms of foregone fiscal revenue. In addition, the Thermal Account that entered into force for the first time in 2012 has provided substantial incentives for renewable energy and energy efficiency investments. Subsidies covering part of the expenses for renovation will be available until 2021. Benefits from these policy measures are also exploited by the ESCO market that has grown rapidly in the last years, becoming one of the largest in Europe.

Overall, an optimal policy strategy aiming at improving energy efficiency in the residential sector should seek to impact different barriers and target segments through a holistic approach pursuing multiple goals coherently, mutually supporting each other. Our study has provided some evidence on this. We could also confirm that an energy efficiency policy package is likely to be more effective if it is maintained over the long-term, while remaining flexible. In this latter regard, the Integrated National Energy and Climate Plans (EC 2016c) that will replace the National Energy Efficiency Action Plans (NEEAPs) and the National Renewable Energy Action Plans (NREAPs) and that will cover the ten-year period 2021-2030, will stimulate Member States to think up new energy efficiency policies with a longer perspective.

A long-term policy horizon could empower the confidence in the private sector that there is money to be made through efficiency. But getting private investments in energy efficiency in the residential sector is challenging. The cliché “the cheapest energy, the cleanest energy, the most secure energy is the energy that is not used at all” commonly used to highlight the advantages of energy efficiency, actually points its greatest weakness from a business point of view: there is, or appear to be, nothing to sell, and thus no profit (Fawkes 2016). Energy providers cannot easily decouple utility profits from energy volumes and ESCOs cannot benefit from economy of scale by selling energy efficiency solution to households.

Nevertheless, large reductions in household energy use are unlikely to be achieved from interventions designed to retrofit buildings alone. Studies on household energy use have found a large degree of variability in energy consumption across identical houses: this means that when it comes to energy consumption the role of the occupant behaviour can be as important as building physics (Santin et al. 2009).

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Sustainability indicators in different type of farms. A case study from Poland.

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Abstract

This article concerns the issue of the sustainable agriculture the sustainability as well as autonomy of farms is a response to social demand in economic terms, it is worth examining the degree of sustainability in a set of farms with different type of production and of different sizes. The assessment of farms employed modified direct Agricultural Performance Indicators which were taken from Tellarini and Caporali (2000). The indicators were calculated by analysing the following features: Primary Production, Yield Plant Production, Yield Plant Sold, Animal Production, External Renewable inputs, Internal Renewable Inputs. For statistical analysis the Statistica 9.0 package and the program CANOCO 4.5 were used. The results show that the indicator of autonomy has a high share of input coming from the farm, and it can therefore be concluded that the analyzed farms are highly autonomous. The indicator of overall sustainability shows that the participation of external input from agriculture is rather small, at levels ranging from 2 to 14% of total input. The indicators/ features that differentiate the most studied group of farms are following: Processed Plant Production, Yield Plant Sold, Indicator of Dependence on Non-Renewable, Indicator of Primary Production to Internal Input, Indicator of Primary Production to the Overall Energy Input Indicator of Sales to the Input from Non-Renewable Sources of Energy and Indicator of Sales to the Overall External Input.

1. Introduction

Sustainability, as a feature of systems established and controlled by man, has become the target of socio-economic development. For one of the major objectives of European Agricultural Policy is to have a sustainable and efficient farming sector which uses safe and environmentally-friendly production methods and provides quality products that meet consumer demands. Therefore sustainability is seen as a key element contributing towards a profitable long-term future for farming and rural areas. Policy makers aim to combine strong economic performance with the sustainable use of natural resources in the field of agriculture (Boel, 2005; European Commission, 2004). Implementation of the principles of agricultural economic sustainability based significantly on eliminating some typical conventional farming features from the sector (Lewandowska-Czarnecka, 2009). A conventional farming system is characterised as a capital-intensive, large-scale and highly mechanized system. The consequences are environmental and social problems, such as reduction of natural resources, soil degradation, reduction of ecosystem health through chemical use, reduction in the number of rural communities, loss of traditional agrarian values, declines in food production quality, farm-worker safety and self-sufficiency. The strategy of increasing the sustainability of agricultural systems is, however, implemented primarily by reducing or eliminating the consumption of processed chemicals, particularly fertilizers and pesticides. It is long term process thus there is a need to find an effective method of assessment of sustainable development. For this purpose, indicators should be used that present clear results, as well as allowing for assessment of the phenomenon. To these indicators belong Agricultural Performance Indicators (API) which are tools used to determine the environmental impact of production system management (Tellarini and Caporali, 2000). Environmental indicators provide ‘a complex message, from numerous sources, in a simplified and useful manner’ (Jackson et al., 2000). Moreover, they provide an important source of information for policy makers (OECD, 1999). Assessment of sustainability can be carried out at the parcel/farm level (Bechini and Castoldi, 2009; Fumagalli et al., 2011; Meul et al., 2008; Pacini et al., 2004; Ripoll-Bosch et al., 2012). The sustainability is connected with an autonomy of farms which is becoming very important in the contemporary economy. It is worth examining the degree of sustainability in a set of farms with different management methods and of different sizes. The aim of the study is to analyse farms in northern Poland in the context of sustainable development by the developing of an indicators method for farm evaluation distinguishing the characteristics that most differentiate them.

2. Material and methods

2.2. Location and typology of farms

The objects of the study were 33 farms located in three voivodships in central-northern Poland. The main criterion for division of the farms was the dominant production method on the farm and the total surface area. The agricultural holdings were divided into 5 groups, creating a rather typical set for the test area: 1. Mixed farms of up to 40 ha; 2. Mixed farms of over 40 ha; 3. Animal farms; 4. Predominantly plant farms; 5. Ecological farms.

2.3. Data collection

An interview method was used to obtain information about the farms, and farmers, and these parameters were treated as independent variables. The interview and observations of the farms were conducted based on a form prepared according to the first author’s experience gained during the project PAMUCEAF FAIR 6-CT98-4193 POPLARS − A MULTIPLE-USE CROP FOR EUROPEAN ARABLE FARMERS. Main elements of the production cycle, e.g. inputs on plant and animal production and the resulting products were covered by the statistical analysis. Annual farm inputs were divided into two main categories: renewable and non-renewable inputs. Non-renewable inputs came only from outside the farm and were pesticides, mineral fertilisers, fossil fuels, gas, furnace oil, diesel, lubricants and LPG. However, within the renewable inputs two sub-categories were distinguished: internal and external renewable inputs. The internal inputs consist of the following components: labour, straw, woods, seeds and manure, while the external inputs include purchase of woods and seeds. The characteristics of farms were filled in once, but constant contact was maintained with owners by collecting information about natural and economic conditions, the production process, agricultural techniques, purchase and sale of products and livestock farming expenditures.

2.4. Metadata

The assessment of farms employed modified part of the large group of direct Agricultural Performance Indicators (API) which were taken from publications of Tellarini and Caporali (2000) that can be proposed for monitoring the status of farms. The following diagram shows the calculated indicators (Fig. 1) and in the appendix (Appendices A.1.).

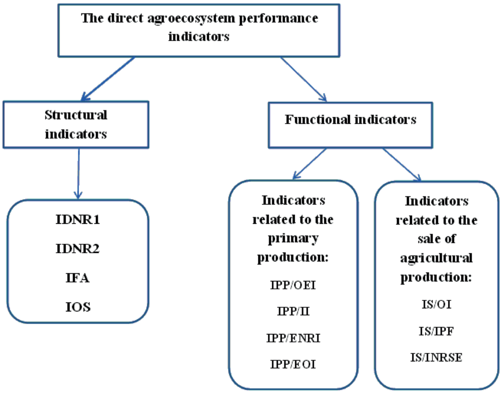

Fig. 1. Agroecosystem performance indicators (Tellarini, Caporali, 2000, modified).

Structural indicators range in value from 0 to 1. A value of 1 represents a farm at the maximum of the relevant parameter. Lower values show the opposite trend. The interpretation of the functional indicators is as follows: 1. A value of 1 means that the energy contained in inputs is equal to the energy in sold products; 2. A value of less than one means that the energy produced in sold products is greater than the energy of inputs; 3. A value greater than one means that the energy contained in inputs exceeds the energy of products sold.

2.5. Statistical analysis

Statistical analysis of the research material encompassed elements of descriptive statistics (classic measurements – the arithmetic mean and standard deviation). To assess the significance of differences in indicators between the distinguished types of farms the nonparametric Kruskal–Wallis test was used with Dunn's test for post-hoc comparisons (Zar, 1999). Significant differences were marked by different letters. For statistical analysis the Statistica 9.0 package (StatSoft 2006) was used. In order to verify which of the set of observed characteristics to the greatest extent compared to differentiate between types of farms, discriminant analysis was performed. Analysis of the CVA was used from the program CANOCO 4.5 (ter Braak and Šmilauer 2002). To assess the relative importance of individual parameters in differentiating groups and their statistical evaluation, stepwise selection of variables was used, along with a Monte Carlo permutation test. In the analysis, all the calculated indicators were determined, and the final model of variation was designed based on statistically significant parameters.

3. Results and discussion

3.1. Indicators of the functioning of the farm

The parameters of the functioning of agro-ecosystems as indicators of ecological rationality are used in the monitoring of sustainability in agriculture (Girardin et al., 1999). A project proposed by Neher (1992) for monitoring the state of agro-ecosystems, combines indicators expressing productivity, the resilience of environmental ecological system and the ability to carry out socio-economic objectives. Lyam and Herdt (1989) recognized, however, that the agricultural system is stable if it does not indicate a trend of diminishing crop production. They proposed an overall rate of productivity, which is total system production divided by total inputs. More economically oriented authors, for example Hansen (1996), concluded that the criterion of farm survival, which is a measure of economic 'vitality', can be taken as a basis.

Table 1. Indicators calculated relative to primary production (mean ± SD).

Group of farms	Indicators related to the primary production			
	IPP/OEI	IPP/II	IPP/ENRI	IPP/EOI
All	1.1±0.3	1.6±0.5	6.4±2.3	4.9±2.2
Mixed, up to 40 ha	1.4±0.5	[b]**2.1**±0.7	6.0±3.2	[a]**4.5**±2.7
Mixed, over 40 ha	1.6±0.5	[ab]2.0±0.7	10.3±4.3	[b]**8.7**±3.1
Animal	1.0±0.2	[ab]1.4±0.4	5.8±1.8	[ab]4.1±1.5
Predominantly plant	1.2±0.2	[ab]1.5±0.3	6.6±1.7	[ab]6.0±1.5
Ecological	1.1±0.1	[a]**1.0**±0.1	5.2±2.4	[a]**2.4**±0.7
Kruskal–Wallis test	ns	p=0.0065	ns	p=0.0022

Considering the various production indicators it can be seen that in the mixed farms there was a doubling of energy in the form of primary production based on energy from renewable inputs coming from the farm (Tab. 1). Meanwhile, animal farms and predominantly-plant farms obtained a slight increase (of about 1.5 times) of energy in the form of products produced. Ecological farms have not reached this excess energy. A farm identified as 'higher input' from Central Italy (Tellarini and Caporali, 2000) obtained a higher value of this index (3.589), while a farm identified as 'lower input' (1.308) achieved a surplus of energy that is comparable with the level of the animal and predominantly-plant farms. Analysing the last two indicators associated with inputs from outside the farm, we can see that all the farms obtained a clear excess of energy in the form of products produced. The values of the IPP/ENRI and IPP/EOI indicators from the article of Tellarini and Caporali (2000) were very close to the values of the predominantly-plant farm in the case of the lower input farm.

3.2.Functional indicators based on sales of products

In the group of indicators related to agricultural production sold outside the farm the average IS/OI for all surveyed farms was 0.3. In the distinguished group of farms the highest value of this index (IS/OI = 0.6) was obtained by predominantly-plant farms and was significantly higher than that of the mixed farms of more than 40 ha or for the animal farms (IS/OI = 0.1), which had the lowest value (Tab. 2). The lowest value of input sales relative to input produced on farm (IS/IPF) was observed for animal farms (0.2) while the highest value was for predominantly-plant farms (0.8). The values of this index for these types of farms, as well as mixed farms of more than 40 hectares, were statistically significant (Tab. 2).

Table 2. Functional indicators calculated in relation to agricultural production sold outside the farm.

Group of farms	Indicators related to the sold products			
	IS/OI	IS/IPF	IS/INRSE	IS/OEI
All	*0.3±0.2*	*0.4±0.3*	*1.5±1.3*	*1.2±1.2*
Mixed, up to 40 ha	[abc]0.3±0.1	[abc]0.4±0.2	[abc]1.1±0.4	[abc]0.8±0.4
Mixed, over 40 ha	[b]**0.5**±0.1	[b]**0.6**±0.2	[b]**3.1**±1.0	[b]**2.7**±1.0
Animal	[a]**0.1**±0.1	[a]**0.2**±0.2	[a]**0.7**±0.4	[a]**0.5**±0.4
Predominantly plant	[c]**0.6**±0.2	[c]**0.8**±0.3	[c]**3.5**±1.1	[c]**3.1**±0.9
Ecological	[abc]**0.2**±0.0	[abc]0.2±0.0	[abc]1.2±0.5	[abc]0.6±0.1
Kruskal–Wallis test	p=0.0001	p=0.0001	p=0.0001	p=0.0001

A similar relationship was found for the other indicators in this group. Indicator IS/INRSE in the surveyed farms was on average 1.5. The highest arithmetic mean was recorded in the predominantly-plant farms, where it was 3.5 and was significantly different from the average indicator calculated for the mixed farms of more than 40 hectares area and animal farms, which had the lowest value, at 0.7 (Tab. 2). The IS/OEI indicator for all surveyed farms averaged 1.2. The highest value was in the group of the predominantly-plant farms (3.1) and was significantly different from the indicator calculated for mixed farms of more than 40 hectares (2.7), and animal farms, which had the lowest value (Tab. 2). The indicators related to agricultural production sold outside the farm took into account the ratio of sales to all kinds of inputs. In the first two categories of such indicators IS/OI and S/NG results indicate that the production cost exceeded the value that was sold. Similar results were obtained by Tellarini and Caporali (2000), where the lower farm input received a value of 0.442 and higher farm input received a value of 0.857 for the IS/OI indicator. In contrast, the IS/IPF indicator value was 0.547 for lower input farm while the higher input farm value was significantly higher at 2.627, meaning that the energy contained in the product sold is 2.6 times greater than that of the inputs. For mixed farms of more than 40 hectares and predominantly-plant farms, the indicators for inputs derived from non-renewable sources and general external inputs show that the farm achieved more energy in the product than in the energy inputs. In these cases, compared to the studies of Tellarini and Caporali (2000) the values of indicators are higher for both the lower farm input (IS/INRSE = 2.985) and for the higher farm input (IS/INRSE = 1.773). The case is similar for IS/OEI, where IS/INRSE was 2.985 for the lower input farms and 1.277 for the higher input farm.

3.3. Structural indicators of farms

3.3.1. The dependence of farms on non-renewable sources of energy

In the studied farms the IDNR1 ratio varied from 0.09 to 0.39. The greatest value of this indicator belonged to mixed farms of up to 40 ha, while the lowest value was for mixed farms of more than 40 ha (Tab. 3). The IDNR2 indicator was more variable within the surveyed farms and ranged from 0.31 to 1.00, with its highest value belonging to predominantly-plant farms and its smallest to ecological farms. There were no statistically significant differences between the two indices in the compared groups. The indicator of dependence on non-renewable resources clearly shows two different situations. The first of these indicators (IDNR1) shows that for most farms between 16 and 25% of total energy input is non-renewable, but the second indicator (IDNR2) shows the percentage for farms to be over 66% non-renewable. However this second indicator takes into account the external input, which explains why the value is significantly higher.

Table. 3. Indicators of dependence on non-renewable energy sources (mean ± SD).

Group of farms	IDNR1	IDNR2
All	0.20±0.07	0.75±0.19
Mixed, up to 40 ha	0.25±0.09	0.73±0.23
Mixed, over 40 ha	0.16±0.04	0.87±0.06
Animal	0.22±0.12	0.66±0.28
Predominantly plant	0.18±0.05	0.71±0.19
Ecological	0.18±0.03	0.88±0.06
Kruskal–Wallis test	ns	ns

3.2.2. Farm autonomy and overall sustainability

Lal (1991) proposed the stability factor, which is the size of the plant or animal production per unit of inputs optimal performance or profit per person. This author's presented method of evaluating the agro-ecosystem also analyses the size of agricultural production per unit of consumption of most deficient or least renewable resources for the most uncertain production level. In turn Sands and Podmore (1993) have proposed the complex indicator of environmental sustainability as aggregations of the ‘sub-indicators’ of soil productivity, stability and system resilience to environmental degradation. Other authors (e.g. Stockle et al., 1994) have proposed an assessment of the sustainability of the system based on nine properties, namely: profitability; effectiveness/productivity; soil quality; water quality; air quality; energy efficiency; natural subsystem structure, represented by the presence of aquatic habitats and populations of wild living plants and animals; quality of life; and social acceptance of the system as a whole. Indicator autonomy shows a high share of input coming from the farm, and it can therefore be concluded that the analyzed farms are highly autonomous. It was found that, over all, more than 63% of input was produced on-farm, with some farms (mixed farms of up to 40 hectares) standing out for 81% of input being produced on-farm (Tab. 4). Tellarini and Caporali (2000) obtained a similar result for two examined farms.

Table. 4. Indicators of autonomy and the overall sustainability of farms (mean ± SD).

Group of farms	IFA	IOS
All	0.72±0.13	0.08±0.10
Mixed, up to 40 ha	0.63±0.15	0.11±0.13
Mixed, over 40 ha	0.81±0.06	0.03±0.02
Animal	0.64±0.15	0.14±0.15
Predominantly plant	0.73±0.12	0.09±0.10
Ecological	0.80±0.03	0.02±0.01
Kruskal–Wallis test	ns	ns

On the other hand, the indicator of overall sustainability shows that the participation of external input from agriculture is rather small, at levels ranging from 2 to 14% of total input. In the study by Tellarini and Caporali (2000), this indicator was significantly higher, at 52 and 84% of total input.

3.4. Key features differentiating farms

The results of discriminant analysis showed that of the 19 analyzed indicators, those which are important in the differentiation of farm groups are: yield plant sold (20.5% explanation of variance between groups), primary production to internal input (9%), sales to input from non-renewable energy sources (8%), sales to overall external input (7.5%), dependence on non-renewable energy sources (5.75%), primary production to overall energy input (8%) and plant yield for fodder (4.5%) (Tab. 5).The CVA ordination diagram shows that the three characteristics of IS/INRSE, YPS and IS/OEI are associated with the predominantly-plant farms as well as the large mixed farms (more than 40 ha) (Fig. 2).

Table 5. Results of discriminant analysis (CVA) with forward selection procedure and Monte Carlo permutation test. Significant parameters are in bold.

Variable	Variance explained [%]	F	p
YPS	**20.50**	**9.02**	**0.002**
IPP/II	**9.00**	**4.37**	**0.002**
IS/INRSE	**8.00**	**4.20**	**0.010**

IS/OEI	**7.50**	**4.31**	**0.016**
IDNR1	**5.75**	**3.60**	**0.008**
IPP/OEI	**8.00**	**6.00**	**0.002**
YPF	**4.50**	**3.50**	**0.022**

Animal farms are best described by YPP, which also describes mixed farms of up to 40 ha. A higher value of IDNR1 distinguished a group including the mixed farms of up to 40 ha and ecological farms (Fig. 2, Tab. 5). Ecological farms have a very low value of IPP/II.

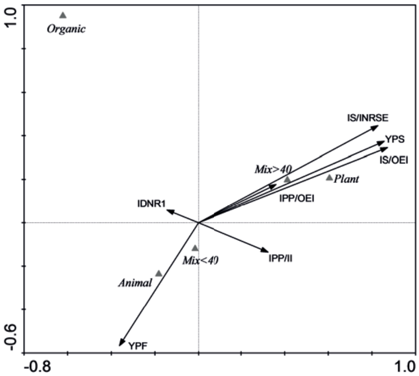

Fig. 2. Model describing the relationship between groups of farms and significant discriminant factors – results of CVA ordination with axes I and II.

4. Conclusion

The mixed farms contribute to strengthening the local circulation of nutrients and matter, and this is a more natural form of management. Intensification within this type of production is based on the purchase of feed for increased stocking and constitutes a risk for ground waters and surface water with excess nutrients. Larger farms with mixed production are the most ecologically correct when the balance of matter is taken into account. With increasing area of farms, farmers decide on specialisation of production. Large farms specialising in plant production removes large amounts of matter from the field then, in its place, introduce mineral fertilisers. The result is the reduction of organic matter in the soil – an undesirable effect threatening the sustainability of farming. The decision process is adapted to farming conditions as well the farmer's knowledge and tradition is still important. It shows that farms in Poland are not still uniform so much.

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Appendices A.1.

Abbreviations and complete names:

IDNR1- Indicator of dependence on non-renewable energy sources
IDNR2 - Indicator of dependence on non-renewable energy sources
IFA - Indicator of farm autonomy
IOS - Indicator of overall sustainability
IPP/OEI – Indicator of primary production to the external overall input
IPP/II - Indicator of primary production to internal input
IPP/ENRI - Indicator of primary production for external non-renewable input
IPP/EOI - Indicator of primary production to the external overall input
IS/OI - Indicator of sales to the overall input
IS/IPF - Indicator of sales to input produced on the farm
IS/INRSE - Indicator of sales to the input from non-renewable sources of energy
IS/OEI - Indicator of sales to the overall external input

Building within environmental boundaries, between need and choice: low-energy, frugal technologies. Learnings from vernacular solutions – a Sudanese case study.

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Abstract

Building design needs to consider that lifetime of its products will likely face environmental and socio-economical changes, and cannot neglect the limits imposed by the geo-biosphere – which is at the same time provider of resources and tank for the waste of our economies. Taking action to face such limits beyond trendy, debatable "green-washing" policies can be either a forward-looking choice or rather something imposed by necessity. The latter is the premise – for instance – of an Italian collaboration between humanitarian NGO *Emergency Onlus* and architecture studio *TAMassociati* in designing hospitals in the African regions of Sahara and Sahel: according to Pantaleo & Strada (2011), many African countries – with their ability to live together with scarcity – represent an example, an opportunity to meditate on some alternative to the mainstream development model, time to time reinventing the thigs. Vernacular building techniques are revisited towards a low-tech innovation that, in a next future, could turn out to be useful also for Western architecture. Some traditional solutions from Sudan and other Countries are here reviewed under a systemic point of view, and presented with the evaluation of their potential advantages in terms of long-term socio-environmental sustainability.

1. Building design within the limits of scarcity

In order to be sustainable and lasting, i.e., able to resist current and future environmental and socio-economical changes, design needs to acknowledge and face such changes. This appears as a particularly suitable good practice when designing buildings, above all buildings that will host services of public interest, since their lifetime is generally projected as far as into the next 50 or 100 years. This implies at least to concede that fewer and fewer resources might be available by then. Although they seem not to have been listened to, the first major warnings about the biophysical limits to growth date back to the Seventies of the twentieth century (Commoner, 1971; Georgescu-Roegen, 1971; Meadows *et al*., 1972; Gorz, 1977). Unfortunately, the limits to the access of resources are not only biophysical, insofar as they involve social consequences such as social inequality, human exploitation, misery and conflicts. Currently, the notion of limit is mainly addressed in talking about the emission of greenhouse gases, and trendy architecture design claims to be taking action by "greening" the balconies or the facades of some yet energy- and resource-demanding steel-and-glass tall buildings. Energy efficiency is more and more addressed, but does not necessarily gives rise to a reduction in energy consumption – in agreement with Jevon's well-known paradox (1865) – being mostly fit in a framework of an increasing general demand. Inside an average Global Northern household, for instance, one might find: heating and air conditioning to have summer temperatures in winter, and viceversa; limitless phone and internet plans to call, share electronic documents, and surf the net *ad libitum* through the most diverse electronic devices, which are replacing books besides regularly replacing themselves due to their planned obsolescence, and so on. In general, the issue of reducing the need for energy and materials altogether is rarely addressed, and a systemic vision is still lacking. This is typical of the so-called "green economy" and "sustainable development", both pursuing economic growth while ignoring scarcity. However, based on the aforementioned changes, in the near future also the Global North might be led to become familiar with the unknown (or unseen) concept of scarcity.

2. African dry regions to imagine alternatives to development

An interesting way to address the (likely) possiblity of such a problematic scenario of scarcity is to measure ourselves with a context where scarcity is the rule, for instance, Saharian and Sahelian regions in Africa. In the following sections, some reflections are presented on a healthcare facility we have been investigating in those areas, namely, the Salam Centre for Cardiac Surgery at the outskirts of Khartoum, Sudan, run and built by Italian humanitarian NGO *Emergency* [1]. Comments are addressed on the forward-looking hybrid solutions employed, based on vernacular building technologies. According to Raul Pantaleo, co-founder of architecture studio *TAMassociati* [2] and designer for *Emergency*, as well as to Gino Strada (2011), co-founder and executive director of the same NGO, Africa can "paradoxically be a laboratory for all the planet, because it can still co-exist – creatively and often lightly – […] with those conditions that the West could need to face in the near future". Building in such a context might represent an opportunity to meditate on an alternative to the mainstream development model, to restart from scratch, where everything is to be reinvented (*ibid*.).

3. The Salam Centre: an introduction to Sudanese case study

The Salam Centre for Cardiac Surgery was built between 2004 and 2007 by *Emergency* NGO, based on a design by architecture studio *TAMassociati* and in collaboration with the Sudanese Ministry of Health. Fig. 1 shows the main facade of the hospital. It provides free healthcare to heart patients coming from over 20 countries[3], being the only hospital of its kind offering free services in Sub-Saharian Africa. The aim of the organisation has been to bring high quality specialistic healthcare – at the same standards as European or United States hospitals – in a deprived area. This choice has often undergone criticism for cost-opportunity reasons, including possible alternative investments to tackle hunger, malnutrition, and primary care instead of highly specialised surgery[4]. By the way, this kind of criticism seems not to take care of the hugely more relevant global and local investements that are *the cause* of hunger and malnutrition worldwide. However, the proposing organisation has always claimed that healthcare – including specialised one – is a universal right, wherever you are from. The Salam Centre is located in Soba, 20 km south of Sudan's capital city Khartoum; it takes up an area of 12,000 squared metres indoor on a lot of nearly 40,000 squared metres on the shores of the Blue Nile river[5]. In the words of our contact person from *Emergency* NGO's humanitarian office, the main driver of the hospital planning and construction phases was just *ethics*. We are actually carrying on a more extended investigation project to find whether this ethics also brings environmental benefits, as well as to track possible positive or crucial consequencies in the society. This will be

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[1] http://www.emergency.it/index.html
[2] http:// http://www.tamassociati.org/
[3] http://salamcentre.emergency.it/En/005/The+Regional+Network.html
[4] http://www.newyorker.com/tech/elements/a-controversial-oasis-of-health-care
[5] http://salamcentre.emergency.it/En/002/Il+Centro+Salam.html

done under a systemic point of view, in particular, by means of the emergy accounting method.

Fig. 1: A detail of the façade of the Salam Centre (photo by architect Raul Pantaleo)

4. Low-energy, frugal technologies

While designing and building its structure, on the left bank of Blue Nile, vernacular solutions and elements were employed, thus merging both the main approaches described by De Filippi and Battistella for architectural projects international cooperation (2014). We will focus on some of the vernacular building techniques, which were revisited towards a low-tech innovation that, in a next future, could turn out to be suitable also for Western architecture.

In the hospital site region, annual average temperature is 45°C. According to Pantaleo (2007), as a cardio-surgical hospital the Salam Centre requires 20°C in its operating theatres, and 24°C in its intensive care rooms, so air conditioning by conventional systems would mean a huge consumption of electric and fossil energy. Despite the oil reserves in the country, *Emergency* NGO decided to provide new, strategically systainable systems based on renewables. This would happen in the same spirit of building a top quality hospital just as it was to be built in any country of the Global North. Therefore, the main energy source available was chosen, the sun (*ibid*.). First of all, passive mitigation techniques were employed to reduce the building energy demand for air conditioning. This was pursued through:

i. the construction of 58-cm external walls with multiple layers of local full bricks, and paneled, insulated air chambers in between (Pantaleo, 2007);
ii. the installation of small double-glass windows protected by sun-screening films[6];
iii. the extensive planting of the land around the hospital with trees and hedges to screen the area from the absorbtion of solar radiation (thus providing environmental mitigation through indirectly resorting to the other local resource available: the Blue Nile's water, used to irrigate these green areas);
iv. the screening of the porticos around the building with panels of loosely twined vegetable fibres (from a local plant similar to a palm), re-functionalising a Sudanese technique used to build beds[6] (as in Figure 2).

[6] http://salamcentre.emergency.it/En/002/004/002/Against+heat.html

Fig. 2: A detail of the porticos of the Salam Centre with the twined vegetal panels on the left and the small double-screen windows on the right (photo by *Emergency* NGO[6])

Such passive mitigation solutions helped reducing the requirements of the hospital, in terms of both financial and environmental costs for its construction, operation, and maintenance. Active solutions to chill the structures consist in a system based on 288 vacuum-sealed solar collectors (covering an area of 900 squared metres). The following information about these solar panels is based on data from Emergency NGO, directly provided to us by its technical division, also summarised and published on the Salam Centre's website[7]. The solar collectors system is able to "cleanly" produce 3,600 kWh, i.e., what would require the burning of over 300 kg of gasoline per hour. Water circulating in copper pipes inside the solar collectors is heated by irradiation, and is then transferred and stored at nearly 90°C inside a 50-cubic-metre reservoir. Hot water produces cooling power by heating up a solution of lithium bromide (LiBr) inside two absorbtion chillers, with the solution reaching the gaseous state thus removing heat and cooling water down to 7°C. Finally, this cold water enters some air treatment units, and cools air to the desired temperatures. Chilled air is then filtered and delivered to the various areas of the building. A spare air conditioning system is present to make up for possible insufficiency of solar energy, composed of two gasoline boilers set up to automatically activate to adjust water temperature inside the reservoir.

Before being cooled by this system, air undergoes a first major filtration from sand and dust (sand storms are frequent in this area at the border between Saharian and Sahelian regions). Filtration is not operated by expensive high-tech filters, but reinterpreting a vernacular technology for ventilation and natural air coolling, typical of other hot and dry areas: Persian wind towers (or *badgir*, see Figure 3), still used in Egypt as well as in some Middle Eastern countries (Dehghani-Sanij *et al.*, 2015).

[7] http://salamcentre.emergency.it/En/002/004/003/Solar+panels.html

Fig. 3: Two tall wind towers cool the courtyard of Persian Borujerdi ha House (1857) in Central Iran

Wind towers conduct prevailing winds into the basement of a building, thus cooling the air without using fuels nor advanced technologies. For the Salam Centre, a wind tower was designed with some innovations: a 60-metre-long labirynth-shaped tunnel was built, able to bring the air from an opening at the first floor (visible in Figure 1) down to the basement, where the impact against all the surfaces it encounters makes the dust and the sand fall down, with the air also cooling down due to the slowing down of its speed[8]. The completion of the air's filtering is done through the spraying of the Blue Nile's water (Pantaleo, 2007). As a result, the air is now 9°C cooler than when entering the wind tunnel[8]. This wind tower system as well as the aforementioned passive mitigations for the Salam Centre are schematised in Figure 4.

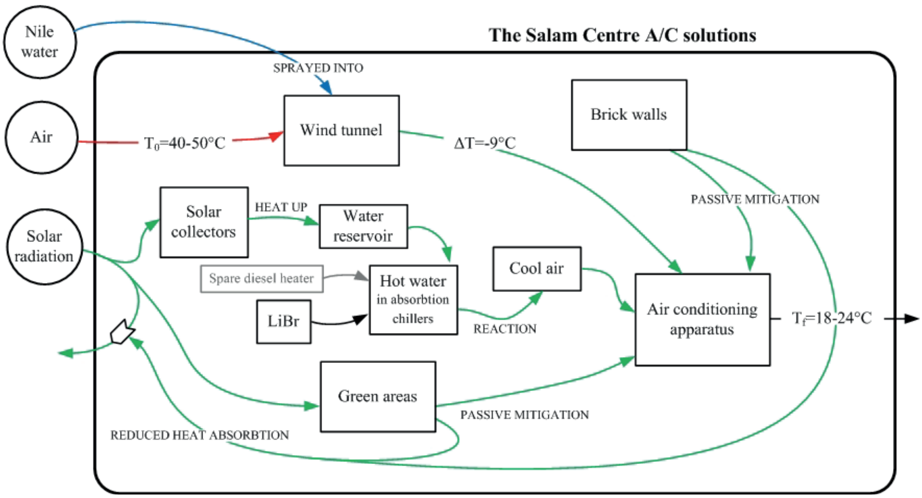

Fig. 4: Scheme describing the Salam Centre solutions for air conditioning through renewables

[8] http://salamcentre.emergency.it/En/002/004/001/Against+dust.html

5. First results of the analysis: eMergy return on investment

Traditional solutions used for the Salam Centre are being reviewed under a systemic point of view, in order to evaluate their potential advantages in terms of long-term socio-environmental sustainability. As illustrated in another study (Cristiano & Gonella, 2017), resource investments in the technologies described in the previous section are yielding high net positive returns in terms of saved nonrenewables: the cumulative energy and material input necessary to realise the wind tower (calculated with an environmental accounting method called eMergy, after "embodied energy" – see Odum, 1996) allows for natural air conditioning, thus saving alternative energy and material inputs (mainly for the production of electricity) for a return ration of over 50:1; according to the same calculation, the solar thermal panel system allows for savings in diesel measurable in a positive energy and material return of three orders of magnitude higher than the required investment (all calculations are made on annual basis). At the same time, the possibility to use clean, abundant, renewable inputs reinforces the hospital system in a medium-long term perspective, when nonrenewables might be scarce or financially expensive, besides preventing the release of greenhouse gases. Through the same eMergy accounting method, a focus will be dedicated to the return on investment of the other low-tech, frugal technologies employed, such as the local bricks or the twined vegetal fibres.

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Energetic-environmental performance of the Brazilian offshore pre-salt oil

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Abstract

The recent offshore oil reserves discoveries at the Brazilian coast indicate the country's potential in becoming an important world actor as oil exporter. To reach this goal, many challenges must be overcome to efficiently extract oil from pre-salt layers, including economic, social and environmental aspects. Focusing on energetic-environmental perspective, the demand for materials and energy needed to extract the offshore pre-salt oil raises doubts about its net contribution to society compared to others energy sources. Thus, this work aims to calculate indicators of energy efficiency under different evaluation scales and the carbon emissions to atmosphere related to the Brazilian offshore pre-salt oil extraction. For this, emergy accounting, embodied energy analysis and life cycle inventory are considered as scientific methods supporting indicators calculation and discussions. Results show a global efficiency of 9.61E3 sej/J, an energy return on investment of 17.5, and a global warming potential of 25.5 kgCO2-eq./barrel (equivalent to 4.0 kgCO2-eq./GJ) for the oil extracted from the Brazilian pre-salt layer. The obtained results indicate similar performance for the studied pre-salt oil compared to other energy sources as found in scientific literature. This work can be considered as the first step towards a deeper and detailed study on the net benefits that pre-salt oil extraction, refining and use can bring to sustainable development of Brazilian society.

Key-words: Embodied energy; Emergy; Global Warming Potential; Pre-salt oil.

1. Introduction

Although recognizing the importance of "pick of all" (Hall and Day Jr., 2009) on the world society sustainability, the population continues to increase simultaneously with the reduction of natural resources. This trend will continue for short and medium periods, because in accordance with the World Oil Outlook[1], the world energy demand will increase 60% during 2010-2040. For this period, the fossil oil representativeness on the total world energy demand would range from 24% to 32%. Numbers from the 2016 Brazilian National Energy Report[2] confirm that Brazil consumed about 115 million m^3 of oil in 2015, which corresponded to 43% of its total primary energy demand. The Brazilian Company for Energy Research[3] points out that Brazilian energy demand will increase from 267 to 605 million of oil equivalent during the 2013-2050 years. All these numbers highlight that fossil oil will still play an important rule on Brazilian development, at least for short and medium periods.

Brazil was dependent on foreigner oil until 2006, but after the pre-salt layer oil discoveries (about 6km depth from sea water level) along with its coast, Brazil has a huge potential to become an important oil exporter (Magalhães and Domingues, 2014). The state-owned oil company Petrobras S.A. has a potential to produce about 1.8 million oil barrels in 2020 from the pre-salt layer reserves[4]. It is expected these new reserves possesses 1.6 trillion m^3 of gas & oil that would overcome in 5 times the Brazilian reserves in 2015. In this scenario, the World Oil Outlook[1] recognizes that

[1] http://www.opec.org/
[2] https://ben.epe.gov.br
[3] http://www.epe. gov.br
[4] http://www2.camara.leg.br/a-camara/altosestudos/pdf/Livro-pre-sal.pdf

Brazil will become a powerful oil producer and exporter by increasing its current production in 1.7 million barrels per day.

The pre-salt oil can provide a series of benefits to the Brazilian society, however some environmental, technological, economic, social and also political issues must be overcome. Notwithstanding, extracting oil from pre-salt reserves demand a huge investment on materials and energy, be at implementation phase as for the operational phase, which raises doubts about its net energy contribution to society. Does the Brazilian pre-salt oil provide net energy to society? Is its net energy return higher than renewable energy sources? What would be the CO_2 equivalent released to atmosphere feeding global warming? According to Magalhães and Domingues (2014), if the Brazilian pre-salt oil is not well managed it could result in curse rather than blessing under an economic perspective. Does the same statement apply under a biophysical (energy and emissions) viewpoint?

It is recognized the importance of calculating indicators able to shown the net energy return of pre-salt oil, its efficiency in using global resources, and its global warming potential to be compared with energy alternatives. This comparison can be considered as important in providing subsidies for decisions makers towards a sustainable development.

2. Methods

2.1. Case study, data source and uncertainty analysis

Pre-salt are geological structures that storage petroleum under thick salt-layers at about 5km depth from the sea-water level; specifically in Brazil, it is located at 8km depth. Figure 1a shows the pre-salt oil reserves in Brazil, totalizing 150,000 km^2, 800x200 km of length, and it is located about 250 km far from the coast. According to Magalhães and Domingues (2014), the conservative estimation for the Brazilian pre-salt reserves points out for 31 billion of barrels, which could double its current oil reserves; however, more optimistic estimations stands for 87 billion of barrels, which could put Brazil close to oil producer countries as Iraq.

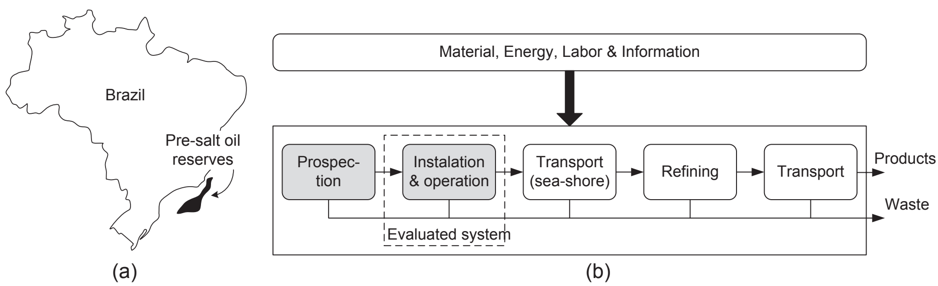

Figure 1. (a) Location of the pre-salt oil reserves in Brazil; (b) Process existing in the pre-salt oil extraction (dashed lines indicate the evaluated system in this work).

Figure 1b shows the main steps needed to make available the fossil oil derivatives to society. Steps are divided in: (i) prospection, the initial technical-economic evaluation to identify the viability in using the oil reserve; (ii) installation & operation, the equipments, machines and all infrastructure are installed and operated to extract oil from pre-salt reserves; (iii) transport, the extracted oil is transported from sea to shore by ships and/or pipelines; (iv) refining, the crude oil is processed and refined into more useful products to society as asphalt, fuel, lubricants, diesel, gasoline, and so on; (v) transport, the final products are transported from refinery to final users (industries, fuel station, residencies, and so on). As the pre-salt oil reserves is a new discovery in Brazil, and also because it is considered as a pillar for the national economic stability, there is a lack of raw data related to material and energy demanded by all steps as described at Figure 1b; even at scientific literature and/or governmental reports. Thus, this work consider as system boundaries the installation & operation step (dashed line at Figure 1b). Although the results could be considered as underestimated for the entire production chain, this work can be considered important as a first effort towards more precise and complete final numbers.

A range of values for the same input resource can estimated according to different and dispersed sources. Recognizing the inherent uncertainties on the used raw data in this study, a Monte Carlo simulation was carried out considering the minimum and maximum values established; the best available data at the time was used. Monte Carlo simulation is a stochastic model that basically generates randomly "n" successive samples further tested against a statistical model. This work assumes a log-normal probabilistic distribution function (PDF) to describe the initial parameters. A value of 10,000 interactions was considered, because instead of using commercial statistical software that usually demands high computational power – and cost –, the Monte Carlo Simulation was performed by using a free-of-charge Microsoft Excell® add-in[5].

In this work, all coefficients that support the usage of scientific methods (described in the next section) in estimating the energetic-environmental indicators comes from the Ecoinvent database (www.ecoinvent.ch) and Emergy database (www.emergydatabase.org); when necessary, scientific papers were also used as source of information and referenced accordingly.

2.2. Energetic-environmental indicators

The following scientific metrics are used in this to reach a multicriteria approach: (a) embodied energy analysis, (b) global warming potential indicator, and (c) emergy accounting. All them were chosen because they are complementary metrics in assessing different perspectives related to sustainability.

The embodied energy analysis (Slesser, 1974; Herendeen, 1998) aims to evaluate the energy demanded directly and indirectly by the system. This method offers a useful indicator on the system energy efficiency under a global scale, by accounting for all embodied "commercial" energy. For this, appropriated energy intensity factors in MJ/unit are used to convert all materials and energy flowing through the system boundaries in their energy equivalents; all they comes from the Ecoinvent Database (www.ecoinvent.ch). The identification and quantification of all these materials and energy flows comes from the inventory phase. The main indicator of embodied energy analysis is the Energy Return on Investment (EROI), which it indicates the amount of energy that is being available to society per energy unit invested in the production process; EROI is an output/input energy ratio. Usually, the EROI is concerned with the human dependence of fossil energy, thus all those resources invested in the production system not originated from fossil fuel are disregarded in the EROI calculation. Services provided free by the environment (i.e. soil, rainfall, etc.) are not considered, as well as services from the larger economy and labor, because the EROI

[5] http://www3.wabash.edu/econometrics/index.htm

is based on the idea that only fossil energy is subject to depletion while natural resources are unlimited.

The second indicator calculated is the global warming potential (GWP). The emission inventory can provides information on global and local emissions. Due to current concerns on global warming, the emission inventory can be considered as fundamental in any study on environmental issues. This present work focuses on the indirect emissions, i.e. on those emissions caused during the production of materials and energy that are further used by the pre-salt oil extraction process. This approach is sometimes called as an "upstream" perspective, because it is concerned with the emissions originated far from the studied system. Although not directly originated by the studied system, the upstream emissions cause a load on environment at global scale. To estimate the indirect emissions, all materials and energy flowing through the system boundaries (from the inventory phase) are converted into GWP in $kgCO_{2\text{-}eq}$. units by using appropriated coefficient factors as available by the Ecoinvent Database.

As the third scientific approach, emergy accounting (Odum, 1996) also focuses on the system environmental performance through a global scale, but this approach accounts for all materials and energy inputs considered as free from the environment (solar radiation, wind, rainfall, etc.) and also the indirect environmental support embodied in human-labor. Regarding scale of analysis, emergy goes back in time to include in its calculations all the work provided by nature to make available a resource. All materials and energy flowing through the system boundaries are accounted in solar emergy units, defined as the total amount of solar energy available that was directly or indirectly required to make a product or to support an energy flow; its unit is equivalent solar Joules (sej). The emergy amount required to produce an unit of each energy or material flow that goes into the system boundaries is refereed unit emergy value (UEV), in sej/unit. The UEV can be interpreted as the quality of energy under a biosphere scale. Emergy accounting provides useful indicators that quantitatively show the environmental performance of studied system. For the purposes of this work, the Transformity (Tr) emergy index is considered, which indicates the system efficiency in converting global resources into goods and services. In other words, the system efficiency in using global resources to extract the pre-salt oil and make it available to society. Tr is a similar index to EROI, but the former considers a global scale going beyond the fossil resources in its calculation procedures (Agostinho and Pereira, 2013).

3. Results & Discussion

Appendix A shows all raw data used in this work that, after running the Monte Carlo simulation, results in the numbers provided by Table 1. Concerning the energy demand, the average value found is 2.91E11 MJeq./yr, indicating that pre-salt oil exploration evaluated in this work demands annually 2.91E11 MJeq. of fossil energy to operate. Although important, this number has low significance when stand at alone because, as usual, the EROI index receives higher importance due to its ability in showing the net energy available to society. According to Silva (2008), about 5.10E18 J/yr will be available to Brazilian society due to pre-salt oil extraction[6]. Now, estimating the EROI by dividing 5.10E18 J/yr / 2.91E11 MJ/yr results in 17.5. This number indicates that for each Joule of fossil energy invested in the pre-salt oil extraction

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[6] 40 billion of barrels in 50 years; 800 million/yr in average; 1 barrel = 158.9 liters; 1 barrel = 6.38E09 J; 800E6 barrels/yr * 6.38E09 J/barrel = 5.10E18 J/yr

results in 17.5 Joules of petroleum to Brazilian society. It is well-know that EROI is dynamic and changes according to energy source, time, and geographical location, however, for a simple comparison, the 17.5 value is within the range of values for fossil fuel as reported by Hall et al. (2014). Precisely, it is closer to the values of oil & gas for Canada in 2010 (EROI of 15), oil & gas for world average in 2006 (18), natural gas for Canada in 2009 (20). Most important is that 17.5 is closer to the performance for photovoltaic energy (between 6 to 12) and wind energy (18), which raises doubts about the real need of pre-salt oil considering that similar net energy can be obtained from renewable sources. The EROI of 17.5 obtained in this work can be considered underestimated because, according to Figure 1b, the installation and operation phases were considered and disregarded all other phases. Thus, the EROI of renewable sources would be even higher, which doesn't supports the usage of pre-salt oil under an exclusive energy efficiency perspective.

Table 1. Embodied energy, global warming potential and emergy results for the Brazilian pre-salt oil.

Method	Value
Embodied energy analysis (in E+11 $MJ_{eq.}$/yr)	
Average	2.91
Standard deviation (σ)	0.43
Confidence interval (95%) = $\mu \pm 1.96\ \sigma$	2.48 to 3.34
Carbon dioxide equivalent released (in E+10 $kgCO_{2eq.}$/yr)	
Average	2.04
Standard deviation (σ)	0.29
Confidence interval (95%) = $\mu \pm 1.96\ \sigma$	1.75 to 2.34
Emergy accounting (in E+22 sej/yr)	
Average	4.90
Standard deviation (σ)	0.65
Confidence interval (95%) = $\mu \pm 1.96\ \sigma$	4.25 to 5.55

Concerning the emissions, Table 1 indicates a total of 2.04 E10 $kgCO_{2eq.}$/yr, which means that the Brazilian pre-salt oil exploration releases annually 20.4 billion kg of global warming gases (GWG). Relating this gross amount with the total pre-salt oil annually extracted, it results in: (a) Global warming potential (GWP) = 2.04E10 $kgCO_{2eq.}$/yr / 800 million barrels/yr = 25.5 $kgCO_{2eq.}$/barrel; or (b) GWP = 2.04E10 $kgCO_{2eq.}$/yr / 5.10E18 J/yr = 4.0 $kgCO_{2eq.}$/GJ. Respectively, these numbers indicate that each barrel of pre-salt oil extracted releases 25.5 kg of GWG, and similarly 4.0 kg of GWG for each GJ of pre-salt oil extracted. For comparison, Agostinho and Ortega (2013) relates a value of 80 $kgCO_{2eq.}$/GJ for ethanol fuel from sugarcane in Brazil. This value is far superior from the 4.0 $kgCO_{2eq.}$/GJ obtained here, which could be explained by the energy source being evaluated (petroleum vs. ethanol) as by the evaluation scale analyzed (the entire production chain vs. installation and operation phases). The same comment can be done when comparing the 4.0 $kgCO_{2eq.}$/GJ with the values reported by Harvey (1993) of 68-73 $kgCO_{2eq.}$/GJ for petroleum production including extraction, production, and transportation phases. On the other hand, the Ecoinvent Database[7] provides a value of 6.8 $kgCO_{2eq.}$/GJ of fossil oil extracted, a value close to that obtained in this work.

Finally, concerning the emergy efficiency, Table 1 indicates an annual demand for 4.90 E22 sej by the Brazilian pre-salt oil evaluated. Estimating the transformity (Tr) value through dividing the emergy demanded by the oil extracted, it results in: Tr = 4.90 E22

[7] Ecoinvent Database, version 3.2 (2015) Database, allocation at the point of substitution, item 194 (petroleum), market for petroleum, GLO, CML2001, climate change, GWP20a, 0.32117 $kgCO_{2eq.}/kg_{oil}$.

sej/yr / 5.10 E18 J/yr = 9.61 E03 sej/J. This number indicates that 9.61 E03 sej of direct and indirect global resources are demanded to extract 1 Joule of pre-salt oil. For comparison, Table 2 shows some published values of Tr for fossil oil. Two groupes can be identified: (i) one integrating the Tr of this present work and the value obtained by Brown et al. (2011), with Tr for fossil oil of 9.61 and 8.07 E3 sej/J respectively; (ii) and a second groupe integrarting all other Tr values ranging from 89.00 to 97.30 E03 sej/J. All works have evaluated the Tr for fossil oil, however, the groupes differ basically on the boundaries evaluated: while the first groupe considers the oil extraction phase, the second groupe considers the entire production chain. According to the emergy theory, for any additional phase added in the evaluated chain, more emergy is demanded, which can explain the differences on the transformities presented by Table 2.

Table 2. Transformity (Tr) values for fossil oil according to different studies.

Transformity in E03 sej/J	Reference	Observation
9.61	This work	Pre-salt oil – extraction
8.07	Brown et al., 2011	Oil (crude) – extraction
89.00	Brown and McClanahan, 1995	Oil – extraction and transport
89.00	Jiang et al., 2008	-
90.70	Odum, 1996	Oil – extraction and transport
93.10	Bastianoni et al., 2005	Oil – extraction and transport
97.30	Zhang et al., 2013	-

All transformities are based on the global emergy budget of 15.83E+24 sej/yr.

4. Conclusions

The extraction of pre-salt oil in the Brazilian coast results: (i) in a demand of 2.91 E11 $MJ_{eq.}$/yr of fossil energy that results in an energy return on investment (EROI) of 17.5; (ii) in an emission of 2.04 E10 $kgCO_{2eq.}$/yr to atmosphere causing a global warming potential of 25.5 $kgCO_{2eq.}$/barrel (or 4.0 $kgCO_{2eq.}$/GJ of oil); (iii) in a demand of 4.90 E22 sej/yr that results in a transformity of 9.61 E03 seJ/J. These numbers indicate similar performance for fossil oil as found in scientific literature, where the differences can be explained by the reduced scale being assessed here that includes exclusively the installation and operation phases. When considering specifically the EROI index for a decision, data from literature for renewable energy sources as wind and photovoltaic appears to be a better choice than pre-salt oil, because besides being renewable they have similar performance for energy efficiency.

It is important to emphasize that scale considered for analysis in this work and all the embodied uncertainties on raw data should be carefully taking into account before generalizing conclusions. Anyhow, this study could be considered as the first step towards further efforts in calculating the energetic-environmental performance of using pre-salt oil as an energy source for the societal development.

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Appendix A. Raw data for the Brazilian pre-salt oil extraction used in this work.

Item	Amount (in E9)		Unit	Composition	Useful life (yr)		Energy intensity ($MJ_{eq.}$/Unit)		GWP intensity ($kgCO_{2eq.}$/Unit)		UEV (E12 sej/Unit)	
	LA	HA			LA	HA	LA	HA	LA	HA	LA	HA
Platform	3.48	9.08	kg	Steel	20	30	3.25	20.69	0.32	2.79	3.69	7.81
Drilling rigs	3.86	6.28	kg	Steel	10	15	3.25	20.69	0.32	2.79	3.69	7.81
Anchorage cables	8.60	12.9	kg	Synthetic fiber (50%)	30	40	50.31	88.21	2.57	6.75	6.48	6.48
			kg	Polyester (50%)	30	40	50.31	88.21	2.57	6.75	6.48	6.48
Tanker ship	16.5	26.4	kg	Steel	30	40	3.25	20.69	0.32	2.79	3.69	7.81
Support ships	0.772	1.87	kg	Steel	30	40	3.25	20.69	0.32	2.79	3.69	7.81
Flexible pipes	9.82	11.2	kg	Steel (20%)	10	20	3.25	20.69	0.32	2.79	3.69	7.81
			kg	Stainless steel (20%)	10	20	49.94	49.94	5.71	5.71	5.90	8.86
			kg	Polymer (60%)	10	20	69.72	69.72	3.53	3.53	6.48	6.48
Risers	4.42	4.42	kg	Steel (20%)	10	20	3.25	20.69	0.32	2.79	3.69	7.81
			kg	Stainless steel (20%)	10	20	49.94	49.94	5.71	5.71	5.90	8.86
			kg	Polymer (60%)	10	20	69.72	69.72	3.53	3.53	6.48	6.48
Christmas trees	0.173	0.39	kg	Steel	10	15	3.25	20.69	0.32	2.79	3.69	7.81
Labor	0.336	0.88	MJ/yr	-	-	-	-	-	-	-	9.66	9.66
Diesel	134	179	MJ/yr	Diesel	-	-	1.34	1.34	0.09	0.09	0.136	0.226

Legend: LA = Lower amount (minimum); HA = Higher amount (maximum); GWP = global warming potential; UEV = unit emergy value.

Obs. #1: All UEVs correspond to an emergy baseline of 15.83E+24 sej/yr and do not account for labor and services. Steel (Bargigli and Ulgiati, 2003; Brown and Ulgiati, 2004). Stainless steel estimated by assuming an energy demand 60% higher than simply steel. Polymer (Andrić et al., 2017). Polyester and Synthetic fiber assumed as the same UEV as for Polymer. Labor (based on Giannetti et al., 2013). Diesel assumed as 25% higher and lower than the value found by Brown et al. (2011).

Obs. #2: Energy intensity obtained from the Ecoinvent Database (www.ecoinvent.ch), version 3.2 (2015), Allocation at the point of substitution, Cumulative energy demand (fossil) method.

Obs. #3: GWP Energy intensity obtained from the Ecoinvent Database (www.ecoinvent.ch), version 3.2 (2015), Allocation at the point of substitution, CML2001 (climate change) method, 20 yrs.

Energy in wastewater treatment: consumption, benchmarking, performance assessment and improvement of efficiency

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Abstract

Energy efficiency in wastewater treatment is attracting more and more. Several indications are proposed to assess the energy performance of wastewater treatment plants, considering the operating parameters that mainly influence the process. However, it appears that the conventional approach used in literature is inadequate to clearly evaluate the energy performance of wastewater treatment plants, whereas the more recent methods proposed are frequently too complex to be applied in practice. For this reason, a methodology based on novel energy performance indicators is developed in this work. The aim is to assess the energy efficiency of a wastewater treatment plant as it is, and to estimate its potential energy efficiency improvement. Based on the analysis of existing plants, some performance classes are identified to propose a benchmarking for wastewater treatment plants in terms of energy efficiency. Only the 6.6% out of a total of around 300 plants presents the highest class of performance, considering the energy consumption related to the organic matter removal. The proposed methodology is also applied to assess and compare several Italian case studies.

1. Introduction

WasteWater Treatment (WWT) is an energy-consuming process, especially in terms of electric energy demand, accounting for about 90% of the total energy consumption (Mizuta, and Shimada 2010). In European countries, it is estimated that WWT is responsible for 1% of the total electricity consumption (Longo et al. 2016). With the increase of world population, and of the effectiveness of WasteWater Treatment Plants (WWTPs), these values are certainly going to increase in the near future. For this reason, energy efficiency in wastewater treatment is attracting an increasing attention of the scientific community.

In order to analyze energy consumption and to identify some methods and measures to improve energy efficiency, a methodology similar to that proposed for energy audits of civil buildings and industrial applications is used for WWTPs. Energy consumption is influenced by several factors, such as size of the plant, stages of treatment, country etc. From the analysis of energy consumption in different WWTPs some general conclusions can be drawn:

- electricity is one of the highest operating costs, roughly 25-30% (Panepinto et al. 2016);
- specific electricity consumption is inversely proportional to the size of the plant (Belloir et al. 2015, Gude 2015, Li et al. 2016);
- highest energy intensive processes are aeration in the biological stage, sludge treatment and pumping (Brandt et al. 2010, Gude 2015, Shi 2011), with an increase up to 50% in case of advanced biological treatment for nutrients removal (Metcalf et al. 2003).

Several strategies for energy saving have been identified, such as optimization of mechanical equipment, replacement of blowers with fine bubble aeration systems, installation of automated control systems for regulation of aeration and modulation of pumps speed. Together with these measures, energy recovery from wastewater and its by-products (Di Fraia et al. 2016) and the use of other renewable energy sources should be promoted, in order to enhance sustainability of the overall process. For the sake of clarity the main stages of a conventional WWTP are illustrated in Figure 1.1.

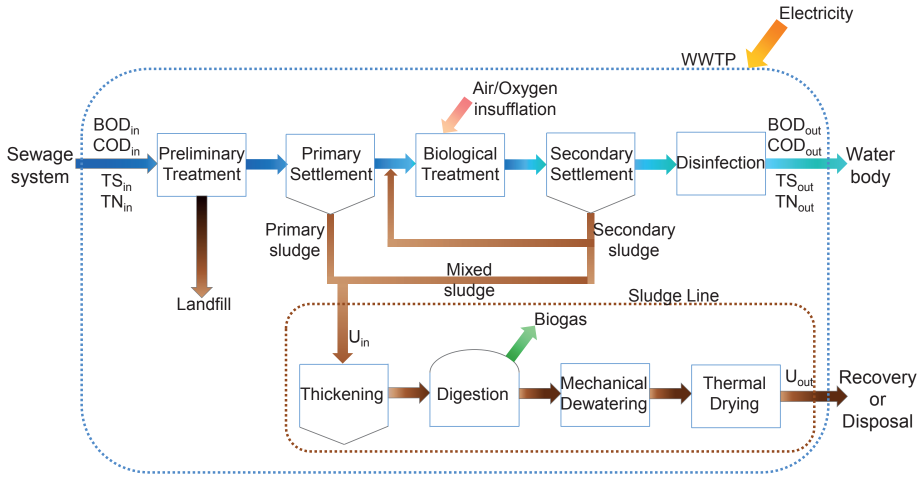

Figure 1.1: Stages of treatment of a conventional WWTP.

Depending on electric energy consumption, the energy performance of WWTPs has been assessed through some indicators (Longo et al. 2016).

$$KPI_V = \frac{\text{Electric energy consumption}}{\text{Volume of treated wastewater}} \quad (\text{kWh/m}^3) \tag{1}$$

$$KPI_{PE} = \frac{\text{Electric energy consumption}}{\text{Population Equivalent}} \quad (\text{kWh/PE y}) \tag{2}$$

$$KPI_{COD} = \frac{\text{Electric energy consumption}}{\text{COD removed}} \quad (\text{kWh/kg COD}_{\text{removed}}) \tag{3}$$

However, it appears that this system of equations does not provide an accurate estimation of WWTPs energy performance. KPI_V is the most used in the available literature (Benedetti et al. 2008, Quadros et al. 2010, Molinos-Senante et al. 2014), although it does not account for the inlet pollutant concentration and its removal efficiency, as well as KPI_{PE} (Shi 2011). KPI_{COD} refers to the electric energy consumption as a function of COD removal, neglecting the volume of wastewater and the other pollutants to be treated.

In order to improve the existing methodology, several novel energy performance indicators can be proposed to assess energy efficiency of a WWTP, and to estimate its potential for energy efficiency improvement. This new methodology developed by the authors is described in Section 2. The main results are illustrated and discussed in Section 3. The proposed methodology is also applied to assess and compare several Italian case studies. Finally, some conclusions are drawn in Section 4.

2. Methodology

In this work a new methodology has been proposed for evaluation of energy performance of WWTPs, based on the relation between the overall energy consumption and specific parameters, taking into account their removal efficiency. It is worth noticing that, when advanced processes are used to improve the quality of final effluent, the overall energy consumption of the plant increases. For this reason, with respect to the existing approach, in this work the pollution removal efficiency is considered in order to evaluate the energy performance of WWTPs.

The novel indicators proposed are derived considering information collected within the ENERWATER Project (CUAS 2015), where more than 500 plants have been examined, through the data coming from literature analysis, technical reports and direct communication with the stakeholders. The information considered come from facilities of different countries, size, treatment cycle, then the sample is representative of different conditions. Energy consumption and the inlet wastewater flow rate are available for all of the plants, whereas the organic matter and total nitrogen concentrations are reported only for the 64% and 30% of the plants analyzed, respectively. This means that, to be really useful for WWTPs stakeholders, such an approach needs to be based on data that can be easily collected.

The first Energy Performance Index (EPI) proposed takes into account the organic matter treatment, since this has been observed to be the highest energy consuming process in WWTPs, due to the aeration stage:

$$EPI_{BOD} = \frac{EE}{BOD_{in}} \quad \left(kWh/kg_{BOD_{in}}\right) \tag{4}$$

where EE is the Electrical Energy consumed and BOD_{in} is the inlet amount of BOD. Both the quantities should be evaluated on a daily basis. With respect to the existing methodology, BOD instead of COD is considered due to the higher number of available data. For all the available data, EPI_{BOD} and the BOD removal efficiency, η_{BOD}, have been calculated. These two groups of data are divided by using some specific quantiles to identify several classes of energy performance and BOD removal efficiency. The lower bound of BOD removal efficiency is assumed equal to the minimum removal percentage required for BOD by existing Italian legislation. The classes obtained are reported in Table 2.1.

Table 2.1: Electrical energy consumption referred to BOD

Class	BOD removal efficiency (%)	EPI_{BOD} (kWh/kg BOD_{in})
A	η_{BOD} >96.8%	EPI_{BOD}<1.51
B	96.8%≥η_{BOD} >92.4%	1.38≤EPI_{BOD}<2.95
C	92.4%≥η_{BOD} >80.0%	2.95≤EPI_{BOD}<5.04
D	80.0%≥η_{BOD}	EPI_{BOD}≥5.04

A similar indicator has been proposed to account for nitrogen influence:

$$EPI_{TN} = \frac{EE}{TN_{in}} \quad \left(kWh/kg_{TN_{in}}\right) \tag{5}$$

where TN_{in} is the influent Total Nitrogen. The classes of TN removal efficiency and EPI_{TN} are reported in Table 2.2.

Table 2.2: Electrical energy consumption referred to TN

Class	TN removal efficiency (%)	EPI_{TN} (kWh/kg TN_{in})
A	η_{TN} >89.2%	EPI_{TN}<6.08
B	89.2%≥ η_{TN} >75.0%	6.08≤ EPI_{TN} <9.74
C	75.0%≥ η_{TN} >51.4%	9.74≤ EPI_{TN} <17.97
D	51.4%≥ η_{TN}	EPI_{TN} ≥17.97

The wastewater volume to be treated has been observed to significantly influence electric energy consumption. Since it is not possible to define a removal efficiency parameter for volume of treated wastewater, the conventional KPI_V, defined in equation (1), is coupled to BOD removal efficiency. The classes of performance are reported in Table 2.3.

Table 2.3: Electrical energy consumption referred to the volume of treated wastewater

Class	BOD removal efficiency (%)	KPI_V (kWh/m^3 WW_{in})
A	η_{BOD} >96.8%	KPI_V<0.33
B	96.8%≥η_{BOD} >92.4%	1.38≤ KPI_V<0.58
C	92.4%≥η_{BOD} >80.0%	2.95≤ KPI_V<0.98
D	80.0%≥η_{BOD}	KPI_V≥5.07

Finally an indicator that accounts for energy Self-Production, SPI, is proposed:

$$SPI=1-\frac{EE - EE_P}{EE} \quad (6)$$

where EEP represents the energy produced from wastewater and sludge, such as by mean of heat pumps, anaerobic digestion, thermal treatment, or in the plant, by installing, as an example, a photovoltaic system. SPI can be calculated for electrical, SPI_{el}, and thermal, SPI_{th}, energy self-production. In addition it can be used to estimate the potential energy saving due to self-production.

3. Results and discussion

The approach commonly used in literature, and described by the system of equations (1-3), is firstly used as a basis for comparison. The relation of electric energy consumption with inlet wastewater, population equivalent and BOD removal is reported in Figures 3.1-3.3. As proposed by the authors, the effect of inlet BOD is also considered, as shown in Figure 3.4. The influence of these parameters on electric energy consumption is evaluated through the Pearson correlation coefficient, R^2, that measures the linear correlation between two variables. As reported in available literature, KPI_V presents the highest R^2, whereas the population equivalent shows a fair correlation. The calculation of equivalent inhabitants vary from country to country and in general PE can be calculated considering the volume of treated wastewater or the influent organic content. This can contribute to reduce the accuracy of PE as parameter for a representative classification. As visible in Figure 3.3 and Figure 3.4, there is a good correlation with BOD: except for few outliers, the cloud point of these cases is more compact than for the previous parameters analyzed.

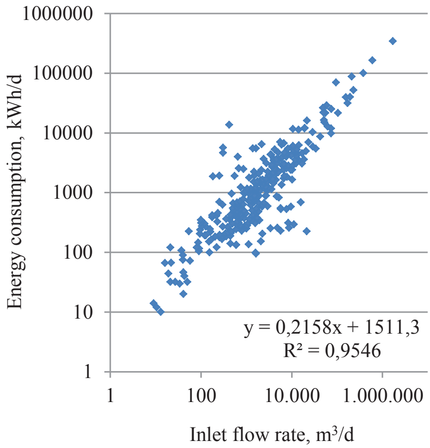

Figure 3.1. Electric energy consumption referred to inlet flow rate, KPI_V.

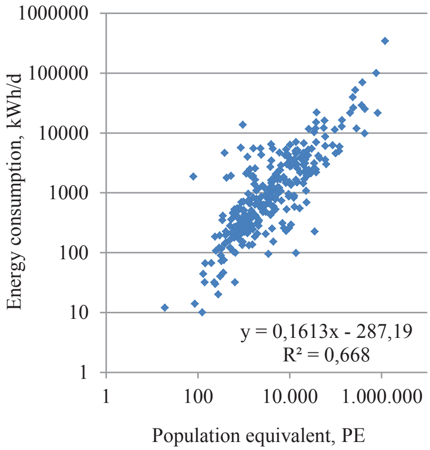

Figure 3.2. Electric energy consumption referred to population equivalent, KPI_{PE}.

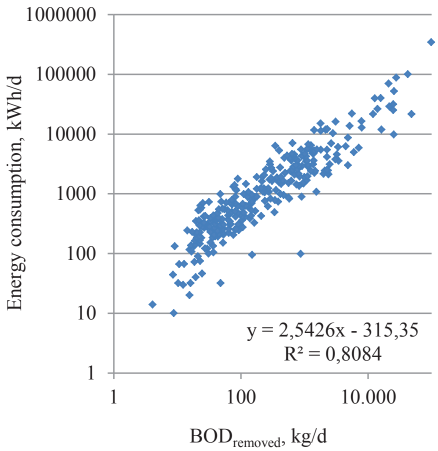

Figure 3.3. Electric energy consumption referred to BOD removed, $KPI_{BODremoved}$.

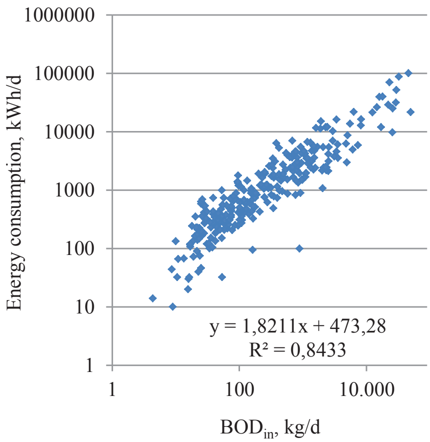

Figure 3.4. Electric energy consumption referred to inlet BOD, EPI_{BODin}.

Although the highest correlation is shown by KPI_V, this indicator neglects the influence of pollutants removal. For this reason, a classification of energy performance classes of WWTPs is here proposed coupling the developed indicators with the removal efficiency of the parameter used. In Figure 3.5, such a classification is illustrated taking into account EPI_{BODin}, as defined in equation (4). The plants with EPI_{BODin} higher than 15 or η_{BOD} lower than 70% are not plotted in order to improve the readability of the picture. Beyond the data of the ENERWATER Project, four Italian plants have been included in the classification. Three of them (P1, P2, P3 from now on), are located in the Campania region, Southern Italy, and the authors performed their energy audits. These plants have been designed and realized between the seventies and the eighties, therefore several actions to improve the energy efficiency have been carried out, whereas other revamping actions to enhance the effluent quality are still ongoing. The last plant (P4 from now on), located in Northern Italy, is the largest Italian WWT facility and one of the most efficient in terms of both quality effluent and energy (Panepinto et al. 2016).

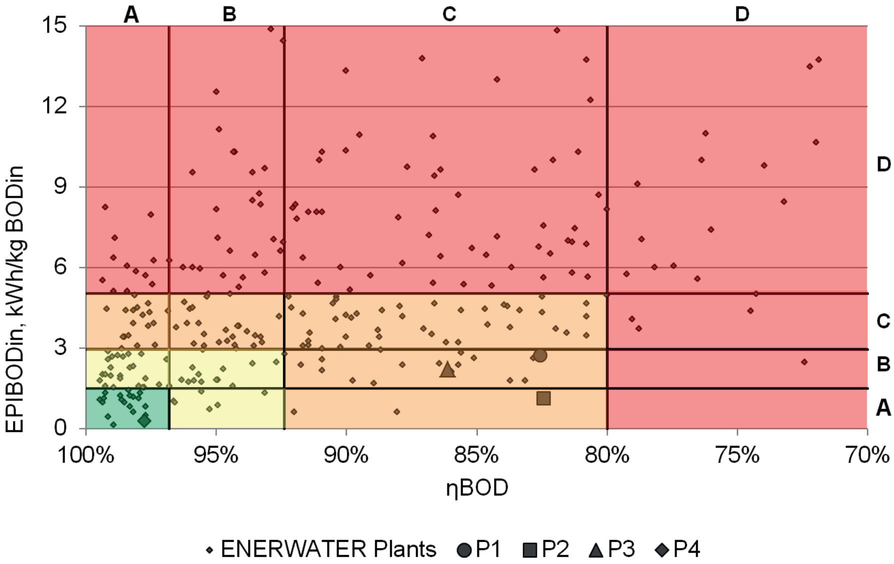

Figure 3.5. Electric energy consumption referred to inlet BOD, EPI_{BOD}

The innovative Energy Performance Indexes (EPI) proposed in this work, and defined in equations 4-8, are calculated for these plants and the results are shown in Table 3.1. As mentioned before, P1, P2 and P3 need to be revamped, indeed their removal efficiency is not high, but the energy optimization actions have made the plants efficient from an energetic point of view. For P2 and P3, the class related to TN is not reported since these plants do not have nitrogen removal. P4 reaches the highest performance, representing a model for the Italian context. Its high energy efficiency is due to both optimization interventions and the cogeneration of about 60 GW h/y of thermal and electric energy.

Table 3.1: Classification of the plants analyzed

WWTP	Energy-BOD	Energy-TN	Energy-V
P1	BC	CD	BC
P2	AC	-	AC
P3	BC	-	AC
P4	AA	BC	AA

Except for P3, the values of EPI_{BODin} and EPI_V correspond, so they can represent a viable method to estimate the energy performance of WWTPs. It has to be said that P3 is characterized by a very dilute inlet flow, that can explain the discrepancy, in terms of energy efficiency, between EPI_{BODin} and EPI_V.

Sludge treatment in P1, P2 and P3 is limited to thickening and mechanical dewatering via centrifugation. In the next few years anaerobic digestion will be implemented, with thermal and electric energy recovery from biogas production. Under this assumption, the self-production indicators for the WWTPs of Campania region after revamping interventions and for P4 at present state are reported in Table 3.2. These indicators are helpful to assess the energy valorization of wastewater and sewage sludge and, as a consequence, to define some incentives measures for the more virtuous WWTPs.

Table 3.2: Classification of the plants analysed

WWTP	SPI_{el}	SPI_{th}
P1	31%	62%
P2	53%	53%
P3	43%	64%
P4	42%	44%

4. Conclusions

This work presents a novel methodology to assess energy performance of wastewater treatment plants. The innovation of the indicators here derived comes from coupling pollutant removal efficiency and the energy consumption related to the same pollutant, in order to define performance classes. The classification proposed is derived using a database about energy consumption of wastewater treatment plants, available from literature. Only 6.6% out of a total of around 300 plants presents the highest class of performance considering the energy consumption related to the organic matter removal.

Several Italian plants, characterized by very different design and management conditions have been also assessed through the proposed methodology. The analysis shows the validity of the procedure, that can be helpful to assess energy performance of existing plants. In addition, it can be used to estimate the potential enhancement achievable through improvement actions or to compare the energy efficiency of a plant before and after revamping interventions, as well as the performance of new facilities.

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Towards an energy efficient chemistry. An assessment of fuel and feedstock switching.

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Abstract

Energy demand for the chemical industry amounts to 15 EJ per year, if only the process-related energy for the manufacture of products from feedstock is considered. When including the energy used to produce feedstocks and the energy content of the feedstocks used in the process, the energy consumption rises to 42 EJ per year, accounting for approximately 10% of the global energy demand or 30% of the total industrial energy demand worldwide (IEA, 2012). Furthermore, this sector generates 5.5% of CO_2 emissions (7% of global GHG emissions) and is responsible for 17% of industrial CO_2 emissions (20% of the industrial GHG emissions). Hence, the reduction of energy demand and GHG emissions is a main target of the chemical industry. By implementing Best Practice Technologies (BPTs) (i.e. the most advanced technologies currently in use at industrial scale) as well as by recycling and energy recovery, cogeneration and process intensification, a global energy saving potential of 10.5 EJ can be achieved in the short to medium term, leading to a reduction of 346 Mt CO_2 per year within 2050 (IEA, 2012). Additional cuts in long-term energy consumption and GHG emissions may arise from the development and deployment of "game changer" technologies, that re-invent the way some large-volume chemicals are made. Although still far from commercial maturity and still facing high economic and technical hurdles, switching to the use of biomass as fuel and feedstock in the chemical industry has a huge potential in terms of fossil energy savings and CO_2 emissions reduction. In spite of this huge potential, several bio-based routes are still more energy intensive than the established fossil-based routes. This calls for increased efforts to foster energy efficiency in all steps of production and conversion processes, in order to make bio-based materials competitive and rewarding from both energy and environmental points of view. During this transition, the carbon and energy impacts of bio-based products need to be evaluated on a case-by-case basis using Life Cycle Assessment (LCA) and other cost-benefit methodologies. In this study, the options of using bioethanol as a fuel to generate energy or as a platform chemical to generate chemical derivatives are assessed, as a case study, in terms of energy intensity and environmental impacts and the consequences on the sustainability of the chemical industry are envisaged.

1. Introduction

According to the IEA (2017), the chemicals and petrochemicals sector results to be the largest industrial energy user, accounting for 28% of the total industrial energy demand worldwide and for approximately 10% of the global energy demand (data updated at 2014). In particular, the production of olefins (ethylene and propylene), ammonia, BTX aromatics (benzene, toluene, xylenes) and methanol accounted for 47% of the chemicals and petrochemicals sector's total energy use. Around the 80% of the total energy consumption is covered by including large-volume chemicals, due to the much lower energy use by a huge number of small-volume products (IEA, 2013). If only the process-related energy for the manufacture of products from feedstock is considered, energy demand for the chemical and petrochemical industry amounts to 15 EJ per year. Nevertheless, the chemicals industry in general uses petrochemical feedstocks and, when including the energy used to produce these feedstocks and their energy content, the total energy consumption rises to 42 EJ per year (IEA, 2012, 2013). Therefore, roughly 60% of the total energy input is consumed as feedstock in the chemicals sector (which includes both energy-intensive basic chemicals and non energy-intensive other chemicals). With specific reference to the EU chemical industry, in 2013 it consumed 53,952 million tonnes of oil equivalent (toe) in different processes, while the total final non-energy consumption attributed to the chemical/petrochemical industry and incorporated as feedstock amounted to 74,717 million toe (Eurostat, 2016). In the case of energy used as feedstock, 81.4% is petroleum products and mainly naphtha (46.9%), while natural gas is covering 18.1% of the total energy. On the other hand, natural gas (25.2%), electrical energy (20.9%) and petroleum products (14.2%) are the main forms of energy used in the processes (Eurostat, 2016).

As a major energy user, the chemical industry worldwide generates 5.5% of CO_2 emissions (7% of global GHG emissions) and is responsible for 17% of industrial CO_2 emissions (20% of the industrial GHG emissions) (IEA, 2012, 2013). In 2005, global GHG emissions across the chemical industry amounted to 3.3 Gt CO_2-eq (+/- 25%), with 2.1 Gt from the manufacture of products and 1.2 Gt from extraction of feedstock/fuel and disposal phases (ICCA, 2009). Focusing on the EU chemical industry, the total emissions amounted to 145 Mt CO_2-eq in 2013 (E-PRTR, European Pollutant Release and Transfer Register, 2016; Boulamanti & Moya, 2017).

According to Cefic (2015), since 1990 chemical industrial production has increased by almost 60%. Nevertheless, in the same period the amount of energy consumed was reduced by 16% and there was a decrease of the total GHG emissions by 55.7% (Boulamanti & Moya, 2017). These results demonstrate the commitment of the chemical industry in Europe in particular, but worldwide as well, in reducing its environmental impact by improving its energy intensity (energy consumption per unit of production). During 2000-14, the average annual growth in the sector's final energy consumption and direct energy-related CO_2 emissions was 2.3% and 2.6%, respectively. In order to meet the ambitions of the international energy and climate change policy and remain on a 2DS trajectory (the IEA scenario, in which global energy related CO_2 emissions in 2050 are half the current level, to achieve the required emissions reduction that climate science research indicates would give an 80% chance of limiting average global temperature increase to 2° C) (IEA, 2013), this trend towards lower CO_2 emissions must be sustained in the long term: annual increases in process energy consumption and direct CO_2 emissions should stay below 3.1% and 2.8%, respectively, during 2014-25, a period in which demand for primary chemicals is projected to increase by 47% (IEA, 2017).

2. Energy efficiency implementation

In the short to medium term, the goal set in the framework of the 2DS for the chemical and petrochemical sector requires a reduction of CO_2 emissions by 1.3 Gt CO_2 by 2050, about 20% less than current levels. To this aim, mitigation options to lower energy and emissions intensities for chemical production processes must be adopted. Fostering best practices among existing plant operators and new facilities as well as removing barriers to enhancing resource-efficient production and waste treatment are key factors to incentivize. Absolute energy use and GHG emissions could increase by 17.5 EJ (186%) and 1.7 Gt CO_2-eq (194%), respectively, between 2010 and 2050, as a result of anticipated growth of the chemical industry (the business as usual – BAU – baseline scenario, in which no further technological improvement takes place). Nevertheless, substantial energy savings and emissions reductions can be achieved by means of the steady progress in implementing incremental improvements, that reflect relatively small and anticipated technological advances in the "normal course of business", and deploying best practice technologies (BPT), i.e. the most advanced technologies currently in use at industrial scale (Saygin et al, 2009). A distinction between BPTs and best available technologies (BATs) has to be made. BATs are different technologies that can be applied in the processes used and can configure the current chemical pathways in order to improve their performance. According to the Industrial Emissions Directive (IED) (EC, 2010), BATs are the most effective and advanced stage in the development of activities and their methods of operation. They indicate the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent or reduce emissions and the impact on the environment as a whole. BATs are technologies which may be in operation in some plants, but are not yet widely proven at industrial scale either technologically or economically. Moreover, technologies either under development or applied in a small scale, but not yet implemented or well established in Europe, are indicated as innovative technologies (ITs). In the IED (EC, 2010) they are named "emerging techniques" and are defined as novel techniques, not yet commercially developed, that could provide either a higher general level of protection of the environment or at least the same level of protection of the environment and higher cost savings than existing BATs.

According to the IEA models (IEA, 2013), in the chemical and petrochemical industry, given the scale of most plants, it is more appropriate to analyze saving potentials by reference to the most advanced technologies that are currently in use at industrial scale (BPTs). Conversely, Boulamanti & Moya (2017) considered BATs as deployed technologies that can be applied in multiple plants and whose integration will enable significant reductions in energy consumption or GHG emissions and calculated the potential for energy efficiency improvement as the difference between the average current energy consumptions and the consumption if BATs or ITs were implemented in the chemical processes.

The energy and CO_2 reduction potentials of key activities such as penetration of BPT-process heat savings, process integration, co-generation, recycling, energy recovery, fuel switching, new technologies and electricity savings have to be carefully assessed. Considering only the manufacturing of the top 18 products (among thousands) which account for 80% of energy demand in the chemical industry and 75% of GHG emissions, IEA estimates show that incremental improvements may reduce by 20% (5.3 EJ) the BAU energy projection and that of GHG emissions by 15% (384 Mt CO_2-eq) by 2050. Widespread deployment of available BPT, through the replacement and refurbishment of existing plants and building of new plants at BPT efficiency level, could deliver even more important savings, estimated in a range between 6.6 and 10.9 EJ of energy saved and between 564 and 854 Mt CO_2-eq of avoided emissions, as shown in Figure 1 (IEA, 2013).

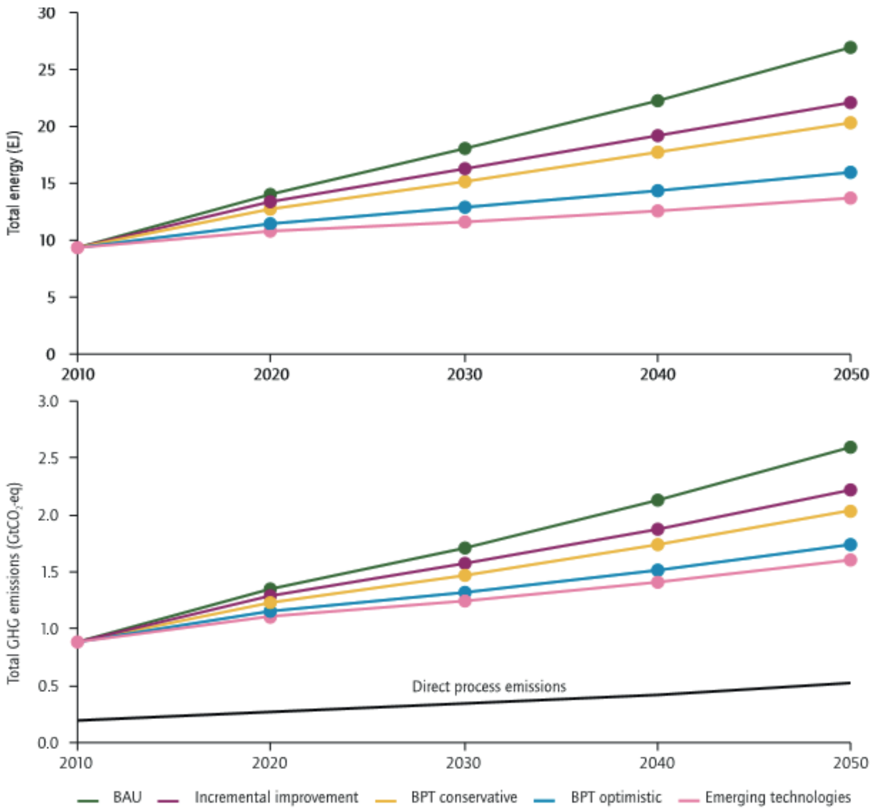


Figure 2.1. Energy and GHG impact of improvement options for the top 18 chemical products to 2050 (Source: IEA, 2013).

Analogously, Boulamanti & Moya (2017) developed a model, including 26 basic chemical products such as fertilizers, basic organic and inorganic substances, polymers and others. In their study, the adoption of best available and innovative technologies resulted to lead to annual savings of 72.5 Mt CO_2-eq and 225 PJ (5.4 Mtoe) by 2050. With these figures, that also include the effect of an increase of the market demand by 45.6%, the total energy consumption of the products included in the study would increase by 39.2%, whereas the GHG emissions would decrease by 14.7%, reaching 129 Mt CO_2 and 5515 PJ (131.7 Mtoe) in 2050.

3. Biomass as a "game changer"

An even larger potential improvement than incremental implementation, BPTs or emerging technologies may arise from the development and deployment of “game changer” technologies, that essentially re-invent the way some large-volume chemicals are made, thus bringing additional cuts in long-term energy consumption and GHG emissions. Game changers follow a more difficult path to development than emerging technologies, often requiring advances on multiple technology fronts. Being of much larger scale and entailing much greater risk, game changers can have quite long development periods, requiring substantial long-term funding, extensive research and development (R&D) and subsequent deployment. Compared to BPTs, however, game changers may initially result in higher energy use (considering the entire scope of energy required to run the considered processes in the future).

In the roadmap developed by IEA (2013) only two potential game changers are mentioned: 1) the use of hydrogen from renewable energy sources to produce ammonia and methanol and 2) the use of biomass as feedstock for chemical products. In particular, the latter is considered as an important potential game changer because intermediate petrochemical products (or building blocks) always require a fixed amount of hydrocarbon feedstock as input. For any given amount of chemical output, depending on the fundamental chemical process of production, a fixed amount of feedstock is required and few opportunities for decreasing fuel consumption are left, unless a major shift occurs toward recycling and bio-based chemicals. The advantages of using biomass rather than fossil substrates to manufacture chemicals and fuels are believed to include opportunities for less pollution, no net CO_2 contribution to the atmosphere, and more biodegradable and sustainable products (Hermann et al., 2007). Using biomass as feedstock reduces GHG emissions in three ways. Firstly, the use of biomass will reduce dependency on fossil fuels, the source of most GHG emissions in chemical processing. The second advantage of biomass feedstocks becomes evident when products are assessed in a Life Cycle Assessment (LCA) perspective, using a “cradle-to-grave” approach. In this case, due to the fully or partly biogenic origin of the carbon contained in bio-based feedstocks, the accounting of emissions includes the fact that biomass materials absorb CO_2 while growing, which can be used to counterbalance against emissions produced during manufacture or even during destruction or waste. Thirdly, biomass sources are renewable, in spite of their higher demand for land use, while fossil fuels are finite and likely to show larger price volatility in the future. But such emission reduction gains must be weighed against the energy requirements for biomass-based production, since several bio-based routes are still more energy intensive than the established fossil-based routes. This calls for increased efforts to increase energy efficiency in all steps of the production and conversion processes, in order to make bio-based materials competitive and rewarding from both energy and environmental points of view. During this transition, the carbon and energy impacts of bio-based products need to be evaluated on a case-by-case basis using LCA and other cost-benefit methodologies (Fiorentino et al., 2017).

4. Bioethanol as fuel or building block?

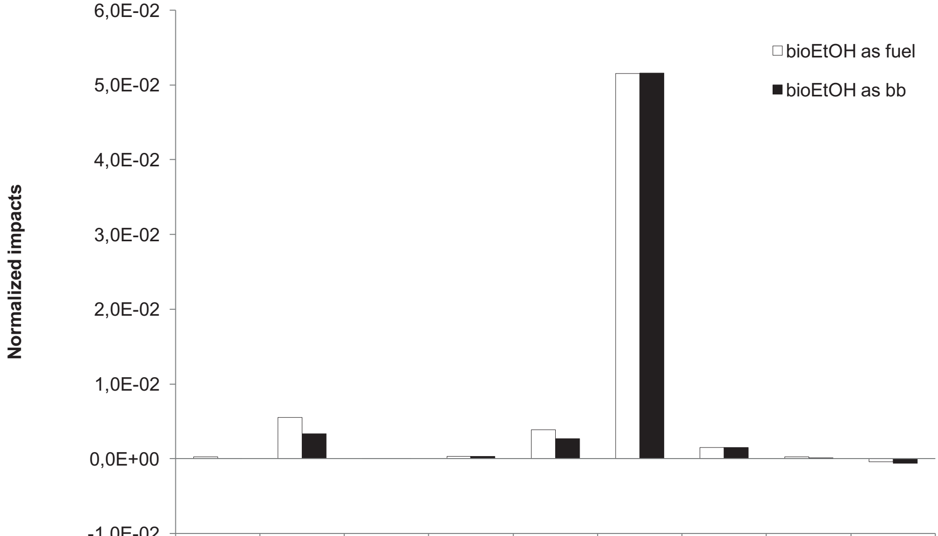
Over the last decade, bioethanol production has intensely increased, due to the fact that bioethanol is mostly used as an alternative transportation biofuel in response to limited supplies and escalating prices of fossil oil and to global warming (Wiloso et al., 2012), with USA and Brazil being the leader producing countries. Total ethanol production in the USA has reached 14810 million gallons in 2015 (Zabed et al., 2017). The rapid development of the bioethanol market has been accompanied by a growing interest in its use as renewable feedstock for the manufacture of bio-based chemicals (Weusthuis et al., 2011). Moreover, bioethanol was identified as one of the potential top bio-based raw materials for the chemical industry (Bozell and Petersen, 2010). Many important chemicals such as ethylene, propylene, 1,3-butadiene, iso-butylene, hydrogen, acetaldehyde, ethylene oxide, n-butanol, acetic acid, ethyl acetate, acetone and dimethyl ether have already been synthesized by means of catalytic conversion of bioethanol. The production of ethylene through dehydration is particularly relevant, since ethylene is commonly used for yielding high volume plastics, such as polyethylenes (high density polyethylene HDPE, low density polyethylene LDPE and linear low density polyethylene LLDPE), polyvinylchloride (PVC) and polyethylene terephthalate (PET), through co-polymerization of mono-ethyleneglycol (MEG) with terephthalic acid. Therefore, growing production and technological advances for bioethanol conversion to bulk chemicals together with the promise of new technologies for cheap cellulosic bioethanol, could work as solid pillars to create competitive biorefining systems based on bioethanol as chemical building block (Posada et al., 2013).

In this outline, it is interesting to assess the options of using bioethanol (bioEtOH) as a fuel to generate energy or as a platform chemical to generate chemical derivatives, in terms of energy intensity and environmental impacts. A preliminary LCA analysis was carried out, assuming that the production of 1 kg of bioethanol allows the avoided production of 0.85 kg of diesel in the case of bioEtOH as a fuel, according to the E85 vehicles using mixtures of 85% bioethanol and 15% diesel, or 0.92 kg of ethylene oxide, in the case of bioEtOH as building block, according to the mass yield reported by Posada et al. (2013). Table 4.1 and Figure 4.1 show, respectively, the characterized and normalized impacts, quantified by means of the LCA software SimaPro 7.3.0 and the impact assessment method ReCiPe Midpoint (H) v.1.05, on a selection of impact categories (Global Warming Potential - GWP, Human Toxicity Potential - HTP, Photochemical Oxidant Formation Potential - POFP, Terrestrial Acidification Potential - TAP, Freshwater Eutrophication Potential - FEP, Terrestrial Ecotoxicity Potential - TEP, Agricultural Land Occupation Potential - ALOP, Metal Depletion Potential - MDP, Fossil Depletion Potential - FD).

Table 4.1. Recipe Midpoint (H) characterized impacts calculated for the use of bioEtOH as a fuel or as a building block (bb), referred to the functional unit of 1 kg of produced bioEtOH.

Impact category	Unit	bioEtOH as fuel	bioEtOH as bb
GWP	kg CO_2 eq	1.801	0.557
HTP	kg 1,4-DB eq	0.655	0.397
POFP	kg NMVOC	0.004	0.002
TAP	kg SO_2 eq	0.011	0.011
FEP	kg P eq	0.001	0.001
TEP	kg 1,4-DB eq	0.335	0.335
ALOP	m^2a	8.094	8.080
MDP	kg Fe eq	0.108	0.060
FDP	kg oil eq	-0.586	-0.801

Categories such as TAP, FEP, TEP and ALOP are impacted at the same extent, whereas for the remaining impact categories, the use of bioethanol as a building block is more convenient than its use as a fuel. A net environmental benefit is gained only in FDP. Further improvements in the achieved results can be gained if second generation substrates (lignocellulosic biomass, non-food crops or bio-based waste raw materials in general) are utilized, thus avoiding the impacts generated by fertilizers (Fiorentino et al., 2014).



	GWP	HTP	POFP	TAP	FEP	TEP	ALOP	MDP	FDP
bioEtOH as fuel	2,61E-04	5,55E-03	8,99E-05	2,94E-04	3,89E-03	5,16E-02	1,49E-03	2,43E-04	-4,27E-04
bioEtOH as bb	8,08E-05	3,36E-03	4,05E-05	2,92E-04	2,67E-03	5,16E-02	1,49E-03	1,36E-04	-5,83E-04

Figure 4.1. Recipe Midpoint (H) normalized impacts calculated for the use of bioEtOH as a fuel or as a building block (bb), referred to the functional unit of 1 kg of produced bioEtOH.

5. Conclusions

The potential to improve energy efficiency and reduce emissions in the chemical industry is substantial and a collective effort is required to all stakeholders. The chemicals and petrochemicals sector has made progress in shifting towards lower-carbon feedstocks and fuels in recent years, but current bio-based routes to chemical products must significantly improve overall energy consumption and cost to be widely used for large-scale chemical feedstocks. Additional research is clearly needed and, during this transition, the energy and environmental performance of bio-based products needs to be evaluated on a case-by-case basis using LCA and other cost-benefit methodologies.

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Including emergy as driver within the activity-based cost framework

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Abstract

Environmental aspects must be considered as a fundamental pillar towards a sustainable development, since the environment works as a supplier of energy and materials for production processes and receives all subsequent by-products for dilution. Although there are several scientific tools available to quantify environmental aspects, they belong to the diagnosis step of a strategic planning, which means that decision makers can or cannot consider those information for a decision that usually are exclusively based on economic purposes. Thus, a good alternative could be integrating environmental issues within the already established and widely used economic methods of system costing; one of them is the activity-based costing (ABC) method. This work aims to integrate the environmental perspective through emergy values into the ABC method. Emergy accounts for all biophysical resources needed to support a production system by considering a donor side perspective and recognizing the quality of energy, so it is strongly related to the sustainability concept. Results show that proposed approach called ABC-emergy presents different numbers than the traditional costing approaches. At principle, the ABC-emergy allows more aligned decision towards company's sustainability by acting on both, the amount and kind of product that should be managed, as well as on the effectiveness increase of a specific company's activity or process. Further efforts will be focused on merging the ABC-emergy approach (sustainability goals) with the traditional ABC (economic goals) to provide multi-objective subsides for decision makers and, finally, make more effective the environmental issues insertion on companies strategic planning. It is expected that environmental issues go beyond a simple diagnosis and begin to be considered as *action in factum* in decisions towards sustainable development.

Key-words: Activity-based costing; Emergy accounting; Sustainable companies; Sustainable development.

1. Introduction

"Freedom in a commons brings ruin to all" (Hardin, 1968). This statement brings since 60's concerns on the limits of human growth, recognizing that humans live in a finite planet with limited resources availability. Advances towards an understanding on the relationship between human and nature has been carried out more densely during last fifty years. Among others experts, Odum (1996) argues that natural capital and ecosystem services are the real source of wealth, in spite of the commons belief that labor and economic capital were such a source. In this sense, diagnose studies by obtaining indicators of sustainability under biophysical bases (e.g. life cycle assessment, emergy accounting, etc.) could be considered as crucial in supporting decision towards a sustainable society. Although providing important figures, those indicators usually have low practical use, mainly regarding management of companies at any scale. The point is that managers consider mainly economic indicators for their decisions, and this pattern hardly will be changed.

Looking towards a sustainable development, efforts have being carried out aiming to include sustainability biophysical indicators in the company's decisions. On this issue, some examples can be found at scientific literature, for instance Thorton (2013) highlights the importance of green accounting by suggesting the inclusion of the so-called asset-retirement obligations (AROs) within the bookkeeping practices. In short, the AROs are a way to account for the action of allowing the company in establishing its operation in return for exacting a promise to clean up the environment when operations cease. Similarly, based on the idea that emergy (with an "m"; Odum, 1996) content of a flow or storage is a measure of value, quality and real wealth, emergy could be considered as a proper measure of the Commons. Under this perspective, Bimonte and Ulgiati (2002) proposed the emergy and environmental taxation schemes (Envitax) as a way to quantify and tax companies. Other example, Campbell (2005) proposed the emergy-based environmental debt accounting as a new scheme for the traditional bookkeeping techniques. All in all, there are possibilities in quantifying, taxing, and even adding environmental loads within the traditional accounting schemes as standardized by the International Financial Reporting Standards (IFRS), however, who will manage the received money and who will decide where that money should be applied to restore and preserve natural capital are questions still without proper answers. According to Ulgiati et al. (2009), this aspect needs special attention because the reinforcement feedback from humans to nature plays a crucial role for the whole process because it keeps the system healthy and able to generate new resources and services.

Rather than taxing companies due to environmental load, a promisor alternative would be considering sustainability indicators within company's decision tools. The idea is to incorporate sustainability indicators in the already accepted and widely used management decision tools by the companies; here, the activity-based cost (ABC; Cooper and Kaplan, 1988) tool appears as the most promising one. It is important to points out that ABC is not related to company's balance sheet, so it is not under the accounting international rules and it is not considered by the government in calculating taxes. ABC is a method, internally used by companies and useful to create scenarios under simulation considering product-cost, production volume, and products diversification, providing subsidies for decisions towards a company's profit increase. As the profit is the current main target by the company's managers, economic drivers are considered within ABC procedure, however, those drivers could be replaced by environmental-related indicators to subsidize decisions for sustainability. Among others, efforts in this sense have being developed by Tsai et al. (2010; 2012; 2015), Bagliani and Martini (2012), and Yang et al. (2016) by integrating environmental cost-accounting and emissions inventory within the traditional ABC, however, none of them recognize the quality of energy, the hierarchical energy scale, and the energy donor side perspective as the emergy accounting does.

This work aims to integrate the sustainability issue into the ABC method. Specifically, it is proposed the inclusion of emergy flows into the traditional ABC method as a driver in managing company's overheads. It is expected that the proposed approach could result in an optimized choice to reach better economic and environmental performances for companies.

2. Methods

2.1. Activity based-costing (ABC): the traditional approach

The traditional costing systems allocate cost to products under an egalitarian way, i.e. the company's total cost is equally distributed by the total amount of products independently of their embodied energy, material or even economic resources. This approach usually results in a lack of detailed information to support a better-based company management, which affects decisions regarding kind and amount of produced products, sales strategy, and profit margin by product (Ponisciakova et al., 2015).

In an attempt to reduce the distortions on company's overhead allocations towards a continuous economic improvement and, monitoring with higher precision the process performance, Cooper and Kaplan (1988) developed the activity based-costing (ABC) system. Ellis-Newman and Robinson (1998) argues that ABC supports decision makers to improve or eliminate all company's inefficient activities, resulting in an efficiency improvement and profitability. ABC framework allocates the company's overheads to products through a different approach compared to traditional costing systems. For this, ABC uses cost allocation drivers in two stages (Figure 1): (i) costs are allocated to activities by means of resource drivers; (ii) then, the activities are allocated to products by means of cost drivers.

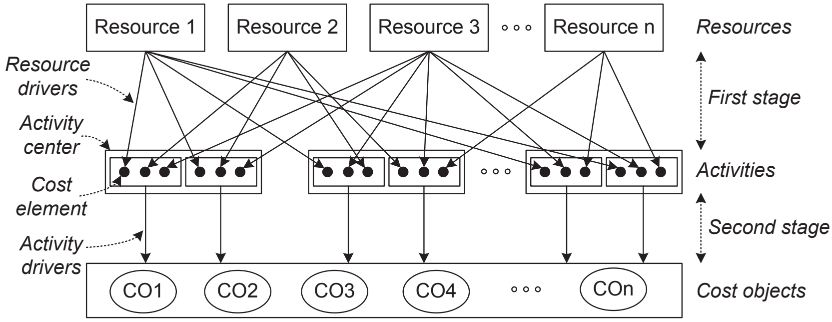


Figure 1. Cost assignment view under the ABC framework. Source: Tsai et al. (2012)

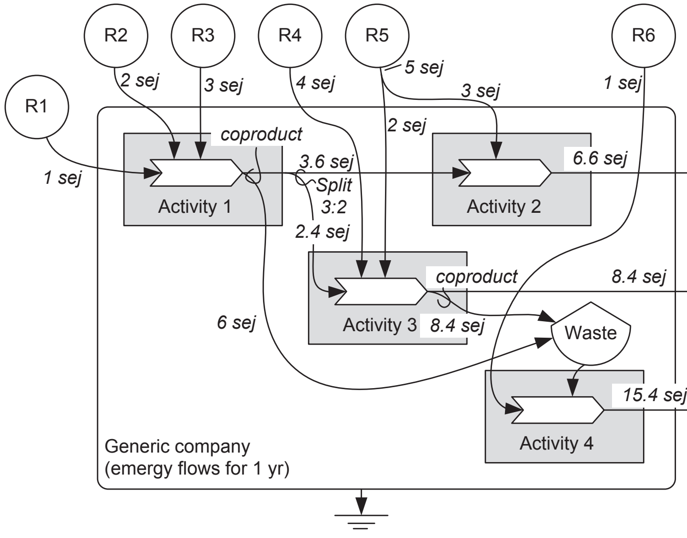
To obtain an effective ABC, it is crucial to use allocation drivers with strong cause-effect relation between resource and activity, and between activity and product. Stronger the cause-effect relation, more precise results will be obtained, which supports a better-based decision (Copper, 1990). The most traditional drivers used within the ABC are production time, industrial area occupied, machine power-rating, machine setup, and hours of labor, which helps to understand which products to eliminate, which materials to change, and what process modify to reach higher company profit.

2.2. Using emergy as ABC's driver

According to Odum (1996; p.7), emergy is defined as "the available energy of one kind of previously used up directly and indirectly to make a service or product". It is routed on thermodynamic bases and system theory, having some characteristics that make it as a powerful scientific-based tool when assessing sustainability: donor side approach in quantifying value, biophysical basis, it recognizes the quality of energy, and it suggests a universal energy hierarchy based on the energy quality concept. Emergy accounting can be applied for different purposes, but its main use is related to the calculation of environmental performance indicators. Among them, the Unit Emergy Value (UEV) evaluates the emergy efficiency or global efficiency in converting resources into goods and services; its unit relates the emergy demanded by the production system (in solar emjoules or sej) with the system output (usually kg, J, or $). Although firstly expressing the efficiency in converting resources into goods and services, the UEV could also be related to the sustainability concept since using lower amount of resources (be renewable or nonrenewable one) could increase the Earth's biocapacity. Indirectly, the same comment can be applied to the total emergy demanded by systems: using lower amount of emergy suggests, at principle, more sustainable systems due to lower amount of global resources needed in its production processes. It is also recognized that a system demanding high amount of emergy from renewable sources has also higher sustainability, however, this doesn't happens in companies because they usually are depend on resources from economy labeled as non-renewable.

Through the increasing number of emergy studies and the strengthening of emergy society (www.emergysociety.com), the amount of UEVs available at scientific literature and databases grew exponentially, making its usage more accessible. Recently, aligned with the concern of its quality maintenance, a larger number of UEVs for different goods and services are available in database and scientific publications, which supports its usage for diverse purposes. Considering the importance of emergy studies in representing sustainability and the availability of UEVs in databases, it could be useful using emergy values as drivers within the ABC method rather than using other traditional drivers as economic, labour hours, and so on. In so doing, the internal company's management will consider also the prerogative of sustainability in its decisions, which would be beneficial for its own management as well as for the entire society through the increase of Earth's biocapacity. The goal is not change the already acceptable and widely used ABC's framework managing method, instead, this work intends to present an alternative in replacing the traditional drivers by emergy flows.

To exemplify this proposed approach, Figure 2 shows the emergy flows for a generic company and the resulting emergy drivers. It must be emphasized that emergy algebra (Brown and Herendeen, 1996) is respected.



Activity	Product 1	Product 2	
1	3.6	2.4	sej
2	3	0	sej
3	0	6	sej
4	0.42	0.58	sej

Figure 2. Emergy flows for a generic company to exemplify emergy-based drivers used within ABC-emergy approach. Legend: R = resources.

3. Results & Discussion

Recognizing the objective of this work is proposing the inclusion of emergy as an allocation driver into the ABC method, we have considered the framework provided by Tsai et al. (2010) to support our calculations rather than elaborating a new ABC for a company. In the referenced work, authors applied ABC for the environmental sector of a company, precisely, the effluent and water treatment plant. For this, differently of using economic or other drivers related to technical efficiency (as the real usage hours of equipments) as usually done, authors have considered drivers as waste emissions (kg), waste water (m^3), water input (m^3), and others as listed in Table 1; it also shows the activities analyzed. This approach can be considered an advancement on the traditional purely economic ABC drivers, however, the drivers used by Tsai et al. (2010)

can exclusively be applied on the industrial activities as effluent and water treatment plant. This restriction should be overcome since the main load on environment usually happens on the demand side of industries, i.e. it is related to the demand for resources as materials and energy for their production processes.

Table 1. Activities and drivers considered by the Tsai et al. (2010) study.

Activity	#	Cost Drivers	#
Preventing air pollution	A1	Waste emissions (kg)	D1
Preventing water pollution	A2	Waste water (m³)	D2
Efficient utilization of water resource	A3	Water input (m³)	D3
Recycling general industrial waste	A4	Recycled general waste (t)	D4
Recycling hazardous industrial waste	A5	Recycled hazardous waste (t)	D5
Disposal of general industrial waste	A6	Disposal general waste (t)	D6
Disposal of hazardous industrial waste	A7	Disposal hazardous waste (t)	D7
Activity for monitoring environmental impact	A8	Internal audit (units)	D8
Activity for environmental training of employees	A9	Time of training sessions (hr)	D9
R&D to curtail environmental impact at the manufacturing stage	A10	Time of R&D (hr)	D10
R&D to curtail env. impact of distribution stage	A11	Time of R&D (hr)	D11
Nature conservation, planting of greenery	A12	Operating space (m²)	D12
Financial support of environmental groups and local community's activities	A13	Operating revenue ($)	D13

Appendix A shows the traditional costing system (TCS) and the ABC through an environmental approach (ABC-env.) as suggested by Tsai et al. (2010). As well know TCS approach is a simplified method and do not distinguish any company’s activity in a separated way, which results in an overhead allocation of about 25.4 million dollars for product “P”, 2.8 million for “Q”, and 92 thousand dollar for all other company products. Although providing some important indication about what product is responsible for the company’s overhead, it is not able to provide any information regarding what activity is the most representative causing that overhead. Thus, the unique possible action that company’s manager can do is related to products, i.e. reducing or increasing the production of that product most influencing overheads, or even replacing that product by others.

Differently from TCS, the ABC-env. distinguishes the company’s activities when allocating overheads and, mainly, it considers different drivers for allocation according to the strong relation between activity and its overhead related-cost. In so doing, Appendix A shows the following overhead allocation for ABC-env.: about 21.7 million dollars for product “P”, 4.7 million for “Q”, and 1.8 million for all other company products. The first reading is that results are different between TCS and ABC-env., because different allocation drivers were considered. This implies that managers can take different decision towards the overhead reduction according to method used for calculations. Notwithstanding, decisions will be based on the meaning of used drivers, i.e. rather than focusing on pure economic purposes as done by TCS, the ABC-env. focuses on environmental issues as those ones listed at Table 1. Under a sustainability perspective, this can be considered as important since environmental issues are now considered for decisions.

The second observation on Appendix A is that ABC-env. allows verifying what company’s activity is affecting more intensively the final results. Thus, decisions can be done not exclusively on the amount and kind of company’s products, but now the activities can also be the target by improvements and/or exclusion looking for the total overhead reduction. In short, the ABC-env. can be seeing an advancement on the TCS in the following two aspects: (i) environmental drivers are strictly related to sustainability issues and they are now considered for decisions rather than exclusively economic ones; (ii) distinguishing the company's activities allows decisions focused on both, products and activities.

Although considered an advancement towards a sustainable development, the ABC-env. still has some limitations that could be overcome by using emergy as company's overhead driver. As a limitations it can be quote the local scale perspective under analyses, which hardly will encompasses the widely concept of sustainability. Emergy can be considered a carrier of sustainability because it reflects all direct and indirect energy (starting from a global budget including solar radiation, tidal energy, and geothermal heat) to make available a good or service. Appendix B show that higher the activity's emergy value, higher will be allocated company's overheads to that activity and product, which makes sense since higher emergy demand express an activity demanding high amount of resources. The following allocation for ABC-emergy is observed: about 11.9 million dollars for product "P", 14.6 million for "Q", and 1.6 million for all other company products. The same existing benefits on the ABC-env. as above described are also observed on the ABC-emergy, however, now the overheads are allocated based on a global resources demand, thus it provides results more aligned to a strong sustainability conceptual model.

Table 2 provides the final numbers obtained for the three costing approaches evaluated in this work. Results are different, i.e. the total company's overhead of 28.255.552 dollars is differently allocated to activities and products. Concerning on products, while TC and ABC-env. allocate overheads mostly to product "P", the ABC-emergy allocate them almost equally to products "P" and "Q". It indicates that while product "P" demands high amount of working machine hours, water consumption, waste emissions, or other driver presented at Table 1, this total energy/material demand has high global efficiency and low influence on the ABC-emergy; on the other hand, product "Q" demands lower amount of resources than "P", but the UEV of these resources are high and inefficient. ABC-env. differs from TCS on products "P" with 15% lower overhead allocated, "Q" with 70% higher, and "others" with 19.5 times higher than for TCS; comparing TCS with ABC-emergy, product "P" receives 53% lower overheads, "Q" with 5.2 times higher and "others" with 17.9 times higher than TCS.

Table 2. Results for three different costing system. Calculations presented at Appendix A and B.

Approach	Product "P" ($/yr)		Product "Q" ($/yr)		Other products ($/yr)	
- (TCS) Traditional costing system	25.368.246	[1.00]	2.795.514	[1.0]	91.793	[1.00]
- (ABC-env.) Activity based-costing using environmental drivers	21.714.801	[0.85]	4.750.389	[1.7]	1.790.375	[19.5]
- (ABC-emergy) Activity based-costing using emergy	11.984.455	[0.47]	14.626.364	[5.2]	1.644.734	[17.9]

Observation: numbers in bracket indicate the relation among the results for different ABC approaches analyzed.

The differences on results were expected since different drivers were considered. Most important is that drivers chosen are always strongly related to the main targets, i.e. whether the aim is to increase profit then economic related drivers must be chosen, whether the aim is to reduce local/regional environmental impacts then those drivers provided at Table 1 must be chosen, but whether the aim is to increase sustainability under its wider concept then emergy drivers must be chosen.

This work presents the first attempt in including emergy as driver in the well-known ABC method, however, the decision maker hardly will choose exclusively the ABC-emergy for a decision since economic aspects are, and it will continuous be, a fundamental aspect for any company. Recognizing this behavior for the economic growth paradigm, more than provide a way to include environmental aspects into the ABC, the next step of this research work will be to propose and evaluate a way to combine both economic and environmental aspects simultaneously to support a decision. For this, the use of goal programming techniques appears as a good alternative. As a limitation of ABC-emergy is the need of UEVs for each activity considered in the costing analysis. However, emergy accounting users are growing up fastly in the last years and more UEVs are becoming available at scientific literature and databases. Other limitation is that ABC-emergy, as well as all other costing method, is focused on the overheads rather than total company's cost (i.e. including all energy and materials demanded for production), so either the ABC is being used, it acts only on part of total environmental load.

4. Conclusions

The proposed activity-based costing based on emergy accounting (ABC-emergy) to allocate company's overhead show different results when compared to the traditional costing (TC) method and to the activity based-costing using environmental drivers (ABC-env.). For the case study considered, product "Q" and "P" receiving respectively 42% and 52% of total overheads, thus both products are the targets of managers towards an increase on company's sustainability. To reach this objective, managers can act on the amount of "Q" and "P" produced by reducing them or replacing them by "other products", or even improving the efficiency (i.e. reducing the demand for resources) of activities A1, A13, A6 and A9 primarily because their lowest rating.

This work is a first attempt towards a more robust ABC method that includes sustainability issues, which will incorporate also a multicriteria decision technique in combining economic and environmental aspects. Maybe, this synergy could be used in practice by company's managers to reach both objectives: economic growth based on sustainable development.

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Appendix A. Activity environmental based-costing (ABC-env.) and traditional costing system (TCS) for the environmental sector evaluated by Tsai et al. (2010).

Activity	Cost drivers	Overheads [(a)] ($/yr)	Product "P" [(b)] (Unit/yr)	Product "Q" [(b)] (Unit/yr)	Other products [(b)] (Unit/yr)	Total [(c)] (Unit/yr)	Unit	Unit cost per activity driver [(d)] ($/Unit)	Product "P" [(e)] ($/yr)	Product "Q" [(e)] ($/yr)	Other products [(e)] ($/yr)
A1	D1	2.657.100	5.603	692	623	6.917	kg	385	2.152.251	265.710	239.139
A2	D2	2.869.640	1.514.182	133.115	16.640	1.663.936	m^3	2	2.611.373	229.572	28.697
A3	D3	544.400	3.918.501	126.132	159.768	4.204.400	m^3	1	507.381	16.332	20.688
A4	D4	528.590	2.675	301	31	3.005	ton	176	470.446	52.859	5.286
A5	D5	2.304.990	1.231	312	16	1.557	ton	1.481	1.820.943	460.998	23.050
A6	D6	2.051.100	1.985	252	277	2.512	ton	817	1.620.369	205.110	225.621
A7	D7	1.318.900	1.002	131	170	1.301	ton	1.014	1.015.553	131.890	171.457
A8	D8	261.160	813	109	165	1.085	unit	241	195.509	26.068	39.584
A9	D9	887.925	219	25	3	245	hr	3.625	790.254	88.793	8.880
A10	D10	4.653.462	42.400	30.400	7.200	80.000	hr	59	2.466.335	1.768.316	418.812
A11	D11	2.573.860	29.400	17.400	13.200	60.000	hr	43	1.261.192	746.420	566.250
A12	D12	684.925	39.872	3.584	1.344	44.800	m^2	16	609.584	54.794	20.548
A13	D13	6.919.500	29.774	3.382	108	33.263	$	209	6.193.611	703.527	22.363
			Activity based-costing using environmental drivers (ABC-env.):						**21.714.801**	**4.750.389**	**1.790.375**
Machine hours		28.255.552	693.120	76.380	2.508	772.008	hr	37	25.368.246	2.795.514	91.793
						Traditional costing system (TCS):			**25.368.246**	**2.795.514**	**91.793**

[(a)] From company's balance sheet; [(b)] Products "P" and "Q", from company's internal quality control report; [(c)] Sum of "P" + "Q" + "Others"; [(d)] (a) / (c); [(e)] (b) * (d)

Appendix B. Activity emergy based-costing (ABC-emergy) for the environmental sector evaluated by Tsai et al. (2010).

Activity	Cost drivers	Overheads [(a)] ($/yr)	Product "P" [(b)] (Unit/yr)	Product "Q" [(b)] (Unit/yr)	Other products [(b)] (Unit/yr)	Total [(c)] (Unit/yr)	Unit	Unit cost per activity driver [(d)] ($/Unit)	Product "P" [(e)] ($/yr)	Product "Q" [(e)] ($/yr)	Other products [(e)] ($/yr)
A1	emergy	2.657.100	9.3E+13	10.0E+13	6.0E+12	20.0E+13	sej	1.3E-8	1.237.408	1.339.860	79.833
A2	emergy	2.869.640	3.0E+13	3.1E+13	10.0E+13	7.1E+13	sej	4.0E-8	1.215.950	1.248.375	405.317
A3	emergy	544.400	9.3E+13	3.0E+13	10.0E+13	13.0E+13	sej	4.0E-9	380.385	123.114	40.902
A4	emergy	528.590	8.2E+13	3.1E+13	7.0E+12	12.0E+13	sej	4.4E-9	362.412	135.242	30.938
A5	emergy	2.304.990	1.6E+13	5.1E+13	8.0E+12	7.5E+13	sej	3.0E-8	493.707	1.564.431	246.854
A6	emergy	2.051.100	10.0E+13	8.1E+13	5.0E+12	19.0E+13	sej	1.0E-8	1.110.189	885.953	54.960
A7	emergy	1.318.900	10.0E+13	3.0E+13	1.0E+12	13.0E+13	sej	9.9E-9	1.008.395	300.522	9.985
A8	emergy	261.160	4.1E+13	7.1E+13	3.0E+12	11.0E+13	sej	2.2E-9	93.435	160.890	6.837
A9	emergy	887.925	8.1E+13	10.0E+13	3.0E+12	19.0E+13	sej	4.7E-9	388.768	484.760	14.399
A10	emergy	4.653.462	2.2E+13	6.1E+13	6.0E+12	8.9E+13	sej	5.2E-8	1.155.488	3.182.842	315.133
A11	emergy	2.573.860	3.0E+13	5.0E+13	4.0E+12	8.4E+13	sej	3.0E-8	915.965	1.535.767	122.129
A12	emergy	684.925	4.5E+13	9.1E+13	7.0E+12	14.0E+13	sej	4.7E-9	215.838	435.513	33.575
A13	emergy	6.919.500	9.6E+13	9.1E+13	8.0E+12	20.0E+13	sej	3.5E-8	3.406.524	3.229.100	283.877
				Activity based-costing using emergy (ABC-emergy):					**11.984.455**	**14.626.364**	**1.644.734**

UEV = unit emergy value; [(a)] From company's balance sheet; [(b)] Total emergy demanded by each product in each company's activity; [(c)] Sum of "P" + "Q" + "Others"; [(d)] (a) / (c); [(e)] (b) * (d)

Improved management of battery and fresh water production in grid connected PV systems in dwellings

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Abstract

This paper evaluates the possibilities of improvement of the management of the batteries and desalination systems of the water consumed in the house and the technical impact in the electrical network

From a model in TRANSYS software validated with the experimental results of a lab-scale pilot installation, dynamic simulations are performed that allow to obtain the hourly values of amount of energy absorbed (purchased) from the network, energy injected into the network, State of Charge (SOC) of the battery and fresh water production and storage in a reservoir for a certain size of PV field, capacity of the battery, strategy of management (charge and discharge) of batteries and operation of the Reverse Osmosis system. Based on the results of the simulation, the optimum size of the storage system (battery) and the photovoltaic field can also be determined from a parametric study.

The design of a system providing electricity by coupling photovoltaic/thermal (PVT) collectors sanitary hot water (SHW) coming from the PVT and evacuated tube collectors (ETC) and fresh water (FW) produced in two seawater desalting facilities (membrane distillation, MD, and reverse osmosis, RO), has been carefully analyzed by means of the dynamic model developed in TRNSYS.

1. Introduction

Grid connected Photovoltaic (PV) systems with batteries for self-consumption in homes is a technology that is gaining acceptance given the advantages it offers. This generation close to consumption (distributed generation) can lead to a reduction of losses in the electrical systems, using a clean local resource (solar energy), and avoiding the centralized energy generation from fossil fuels and its environmental impacts. Demand management systems are necessary to optimize the system, reducing the amount of energy that must be purchased from the grid and the amount of surplus of energy generated, thus maximizing the economic profitability of the system and the degree of self-consumption achieved. In many areas, particularly in Mediterranean countries, the electrical infrastructure is developed and reaches many places where there is no access to public drinking water networks and therefore brackish water from wells or salt water from the sea, etc. must be desalinated.

Apart from producing energy and water with hybrid techniques and renewable energy sources (RES) in cogeneration schemes, there are very few examples of the analysis of tri-generation or poly-generation schemes involving seawater desalination and RES. In [1-2], a poly-generation system based on PVTs, a LiBr-H2O chiller, and a MED distiller, with a back-up biomass heater was simulated and optimized in TRNSYS® with weather data from Naples, Italy. A similar scheme could be optimized by GAMS in its design and operation if conventional energy sources are neglected in the superstructure presented for a polygeneration applied to tourist sector [3]. In [4], a PV system for brackish water desalination by electrodialysis and electricity generation was presented. But the combination of hybrid techniques for both RES and desalination, which also includes SHW, has not been studied in detail yet. Thus, this paper presents the design analysis of a solar PVT+MD/RO installation which allows providing power, SHW and fresh water at a much reduced demand scale in isolated areas. This hybridization is a technically possible solution and its profitability will depend on alternative costs to provide water and energy by a network or even local transport [5].

Taking into account the variability of the renewable energy sources, a dynamic simulation is required in order to model and then to assess the performance of the transient processes occurring in that scheme. Dynamic simulation of this trigeneration system was performed in TRNSYS software (v16). Its modular design easily permits to analyze the main design parameters of each component but also the overall performance of the scheme proposed, according to scheduled energy and water demands. This work presents the base design of a small hybrid-trigeneration pilot plant, which has been erected at the University of Zaragoza. In four PVTs (230Wp each) solar energy is collected and transformed into thermal energy and electricity [6]. With them, the annual demand for SHW in the facility is obtained.

The hourly consumption data are taken from the consumption profile considered by the electricity system operator in Spain, with an annual consumption of 3500kWh / year, and photovoltaic production data have been obtained from a real plant installed in Zaragoza, Spain. The total demand for fresh water is estimated at 106.4 cubic meters per year and is obtained by desalination of seawater with a Reverse Osmosis (RO) system of 110W which allows the production of 35 liters/hour and a Membrane distillation (MD) module (Spiral wound, Permeate Gap Membrane Distillation type, PGMD) with a maximum distillate of 20 L/h. An ETC of 1.4 m2 has also been installed to achieve higher temperatures in the water, since desalination by MD requires higher temperatures (it is a fundamentally thermal load, since the amount of energy it requires is negligible, being only necessary the actuation of a small pump). Finally, two batteries of 250 Ah and 24 V were installed. The total SHW demand is estimated in in 37.2 m3/y [7]. In a previous paper [8] optimization was concentrated in the maximization of the MD distiller. This was found by varying the tank temperature or the flow rate operating in the MD. Thus, SHW is the same in base case and optimum case. However, a 7% power production increment was found in optimum case with respect the base case, and it was increased a lot the MD production (35%). Water, SHW and power costs found in the optimum case are around 3.15 €/m3, 3.84 €/m3 and 0.10 €/kWh respectively, being this scheme one feasible alternative for small isolated family homes. Nevertheless, water produced by MD presents by far the highest cost, and those costs are not competitive in grid-connected systems, especially for the water network.

In grid-connected solar systems, much more flexibility is obtained by the installation of a small capacity of electrochemical batteries [9], which help achieve additional objectives such as reducing the energy absorbed by the grid (increasing the self-sufficiency factor, sometimes called autonomy factor, or autarky) and / or reduce the amount of energy injected into the grid, thereby reducing losses in the electricity grid. There are zero-injection devices on the market that, when the energy produced is higher than the demand and the batteries are completely charged, prevent the injection of energy into the public grid, for example by making the PV panels far from the point of maximum power, so that only produce the energy required in the installation. This is not the option that has been chosen in this paper, but it is considered that the excess energy is injected into the network. By the injection of this energy can receive some money or not. Related to this last point, although not identical, is the objective of maximizing self-consumption, that is, the in situ use of the energy produced by the panels.

The production of water by RO can be considered as a deferrable electric load, since there is an accumulation tank that can be filled, for example when the generation of power is greater than the demand and the battery is completely charged or when the price of electricity is cheaper, (to buy from the network). If at any given moment more water is needed than is left in the tank, energy from the PV field can first be used. If at that time there is not enough irradiance, it is decided whether to use electricity previously stored in the battery or if the SOC of the battery is low, or at that time the electricity price of the network is very low, absorb the energy from the grid. In this paper, two options for producing water have been considered: MD and RO, and the latter with two possible strategies: to connect RO to the electricity grid at night and also to use the excess energy from the solar field to store water in the tank for the next day when the battery is full (RO1) and RO2, operating the RO only when the energy of the panels is greater than the electrical demand and the battery is full (thus) reducing the amount injected into the network.

Another aspect of interest is the appropriate size selection and battery management to achieve the increase in the average useful life span. Batteries are an expensive component whose useful life is very dependent on their management, so that they only support a number of cycles before reaching the end of their life, aspect that is usually considered that is reached when after a full charge no It reaches a value higher than 80% of its initial nominal capacity. Deep overcharges and over-discharges, as well as staying for a long time with SOC levels too low are factors that affect the lifetime of the battery. In that article we will consider the electric charge computation method to evaluate the number of battery life cycles. It will analyze how the different management strategies influence the battery life.

In summary, this article analyzes the behavior of a PVT installation with electrical storage that feeds a typical house in Spain, and also allows the supply of fresh water with MD and RO, which will be considered as a differentiable load (to achieve better integration With the electrical network and better use of the batteries).

2. Energy parameters for the analysis

The exchange of energy with the grid Es(Wh), is split into their positive and negative values in order to separately calculate the surplus (energy injected into the grid) and the shortage of energy (energy absorbed from the grid) . In [9] some interesting parameters for the analysis of hybrid grid connected power systems were presented. In this paper the following parameter are analyzed

Self-sufficiency factor (%) = 100-AEA where (AEA) is defined as the sum of all the energy absorbed from the grid along the year of the simulation, divided by the annual energy demand. AEA represents the fraction of the annual demand that the residence owner should buy to the grid to meet his energy requirements.

Additionally the surplus of energy is accounted for through the Annual Energy Injection (AEI), the accumulation of all energy injected into the grid along the year divided by the annual energy demand. The AEI is the fraction of the annual demand that due to full charged batteries and is injected into the grid (in case of a favorable legislation, this energy is sold at a determined price).

$$AEA(\%) = \frac{\sum_{h=1}^{8760} \left| E_{s,h}(E_{s,h} < 0) \right|}{\sum_{h=1}^{8760} \left| E_{L,h} \right|} x100 \qquad AEI(\%) = \frac{\sum_{h=1}^{8760} \left| E_{s,h}(E_{s,h} > 0) \right|}{\sum_{h=1}^{8760} \left| E_{L,h} \right|} x100$$

$$Self - consumption\_factor(\%) = \frac{\sum_{h=1}^{8760} E_{g,h} - E_{s,h}(>0)}{\sum_{h=1}^{8760} \left| E_{g,h} \right|} x100$$

Self-consumption factor (ratio between the energy consumed directly from the generation (+ battery) in the installation and the energy generated in the installation (PVT)). Physically it is the quantity generated in the installation that is instantly consumed in the installation itself. Mathematically it is the sum of the hourly values of the energy generated minus the injected energy, divided by the total energy generated in a year.

From the utility point of view, the quantification of the energy loss in conductors, results also of high interest. The definition of RLC can be found in [7].

2xPVT	1xPVT	OI1	OI2	MD	TV	Case
	X					1
	X		X			2
	X		X	X		3
	X		X	X	X	4
	X		X		X	5
	X	X				6
	X	X		X		7
	X	X		X	X	8
	X	X			X	9
	X			X	X	10
	X			X		11
	X				X	12
X						13
X			X			14
X			X	X		15
X			X	X	X	16
X			X		X	17
X		X				18
X		X		X		19
X		X		X	X	20
X		X			X	21
X				X	X	22
X				X		23
X					X	24

Table 3.1. Simulated cases

3. Results

In order to analyze which method and strategy of operation is most convenient, the cases shown in Table 1 have been simulated, where RO1 means that the operation strategy for RO Consisting of consuming at night to ensure a production of water equal to the daily demand and also in the periods in which the generation is higher than the electric power consumption and the batteries are full; RO2 consists of only when the generation is higher than the electric power consumption and the batteries are full; MD is desalination by Membrane Distillation, and EVT stands for Evacuated Tube Collectors. 2PVT is in the case of installing the double capacity of PVTs than in 1PVT. Some interesting results of the simulations are shown in the following.

Obviously, by the strategy, more water is obtained in case 6 (RO1) than in 2 (RO2) (which is only used when there is excess of energy). When there is electricity generation in PVT and batteries, the battery charge is prioritized. Only when the generation is higher than the electric power consumption and the batteries are full does the RO operate for fresh water production that it is accumulated in a tank. Excess energy will be injected into the network. For this reason, with batteries the production of water is reduced. However, with either RO strategy, enough water is produced to satisfy consumption. With batteries the amount of water produced is much more adjusted to the demand than without battery with strategies 2 and 6. The situation of operating the RO only when there is energy is practically optimal in this option adding a few batteries. The strategy of operation consisting of consuming at night to ensure a production of water equal to the daily demand and also in the periods in which there is energy provides more than the water required annually. Although energy is absorbed mainly in periods when the price of electricity is low, it results in an increase in the economic cost. However, with the MD and PVT panels (case 11), little more than 50% of the required water is obtained (because sufficient temperature is not reached). A situation that increases by more than 70% when adding vacuum tubes (case 10). As it is a fundamentally thermal load, no difference can be seen when adding batteries. It has also simulated the situation of having twice as many PVT panels, in order to see if this could produce a quantity of water equal to the demand With double PVT panels (cases 22 and 23), the MD is still not enough. In later sections we will see what implications it has in addition to the other parameters. In contrast, AEA values (and thus self-sufficiency) greatly decrease, but AEI and losses increase (almost twice as much as in the base case) and the self-consumption factor falls (up to 0.6).

Self-sufficiency and self-consumption factors: The presence of batteries increases the autonomy. Greater autonomy is obtained in case 6.

The AEI is smaller with the additional consumption of the RO, and of course, even less in case 2, where consumption is only when there is excess of energy generation (ie, instead of injecting). Even without batteries, introducing RO reduces RCL, because it decreases AEI. Therefore, the electrification of fresh water production is much better, rather than operating thermal systems (MD).

From the figure 3.1. it is clear that the number of equivalent cycles is much lower with large values of battery capacity, so it will last almost 6 times longer with a battery D = 3, than with a battery D = 0.5. The least equivalent cycles are obtained for cases 9 and 8. Interestingly, it is seen that by doubling the size of the battery (and therefore the initial investment cost), the batteries last twice as long. Therefore, a superior battery is desirable, since the cost over the useful life would be the same, but much better values of network integration and self-consumption are obtained

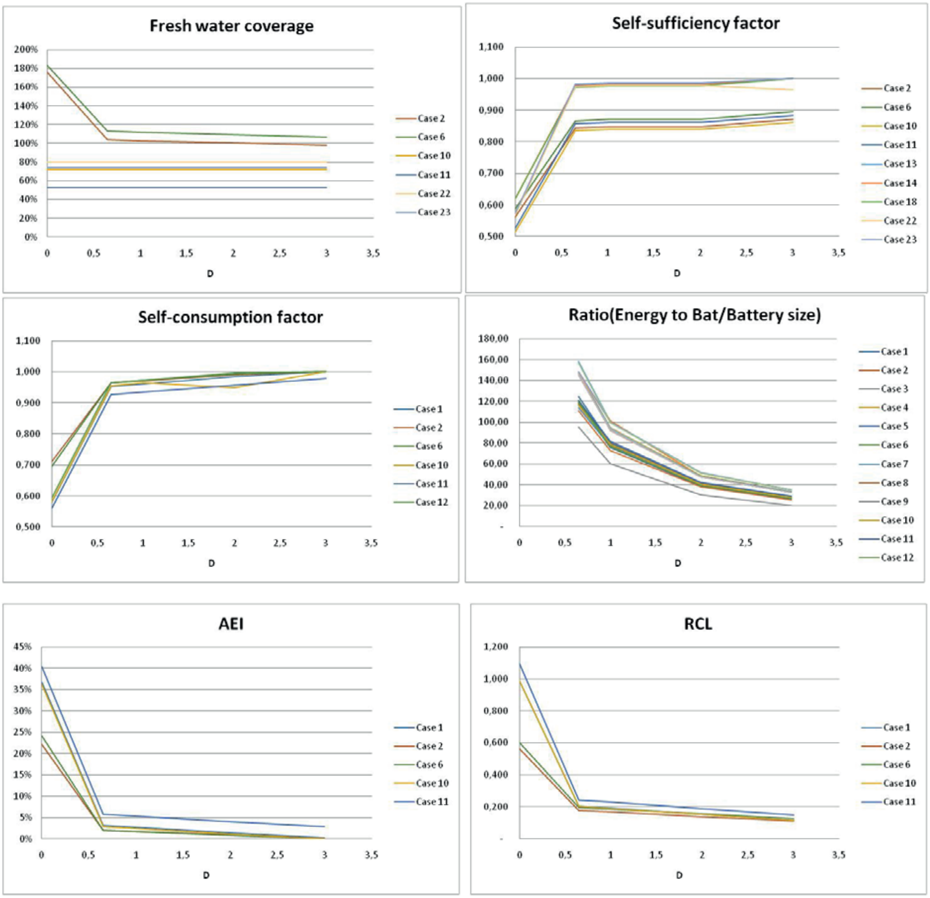

Figure 3.1. Fresh water coverage, self-sufficiency factor, self-consumption factor, equivalent number of cycles, AEI and RCL in different cases

Conclusions.

It is better to desalinate with RO than with MD., The required water can be obtained by only taking advantage of some of the energy that would have to be injected. This is achieved by increasing self-consumption, autonomy and reducing network losses. Putting a small amount of battery improves network integration and self-consumption. However, the bigger the battery, the longer it will last.

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Constructal Law and Thermoeconomic Optimization

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Abstract

The paper introduces the concept of Thermoeconomic Environment and discusses how the Constructal Theory can be applied to the productive structure of an energy system. In this way, the optimal criterion of minimum energy cost of the product, generally assumed by the Thermoeconomic Optimization, can be regarded as derived from the Constructal Law, when the flow of useful product through the productive structure is considered as the characteristic flow of the system. In consequence of the evolution prescribed by the Constructal Law, it can be highlighted that recycling flows may arise in the productive structure and that residues and sub-products cannot be indefinitely accumulated. In this process, a crucial role is played by the framework of the Thermoeconomic Environment. In the outlined context, the evolution of energy systems toward highly interrelated productive structures can be regarded as a consequence of the Constructal Law.

1. Introduction

The paper introduces the concept of Thermoeconomic Environment and discusses how the Constructal Theory can be applied to the productive structure of an energy system, in spite of being the latter a network of functional relations among components (in the abstract space of possible productive interconnections), rather than a stream of physical flows. In consequence of the evolution prescribed by the Constructal Law (CL), it can be highlighted how recycling flows may arise in the productive structure and that the optimal criterion of minimum energy cost of the product, generally assumed by the Thermoeconomic Optimization, can be regarded as consequence of the CL. Therefore, residues and sub-products cannot be indefinitely accumulated but they have to be generally converted into some kind of product by different (new) production processes, supporting the parading of the *Circular Economy*. In this approach, a crucial role is played by the framework of the Thermoeconomic Environment, introduced in the following. Finally, the evolution of energy systems toward highly interrelated productive structures, with multiple recycling flows, can be regarded as a consequence of the CL.

2. Thermoeconomic Optimization

The Thermoeconomic Optimization (TOP) can be generally defined as the effort of achieving a minimum consumption of total resources for obtaining a set of required products (named *P*). The key points are:

i) the total resources include both energy and material streams (the *Fuels F*) consumed at local level as inputs of the production process and all resources *indirectly* consumed for making all the plant components involved in the production system and for maintaining and operating the plant as a whole (the so called flows of *fixed capital Z*);

ii) all resources are regarded as *energy resources*; therefore Fuels *F* and fixed capital *Z* have to be consistently measured.

In this perspective, the flows of fixed capital *Z* may be regarded as the indirect energy expense in order to arrange a proper set of constraints, for the energy conversion processes, which allow the formation of the required products *P*. Nevertheless a problem arises from these general definitions: How different energy and material fuel streams and different kind of fixed capital can be consistently evaluated?

Different answers have been suggested in Literature by different kinds of analysis which, implicitly or explicitly, are supported as possible back ground for the TOP of goods and services production. Each analysis has positive aspects, but some draw back too, in view of TOP. For instance, Embodied Energy Analysis (EE) (Bullard and Herendeen, 1975) uses energy to measure all flows consumed and produced by both natural and technological systems. In this way the *qualitative* difference between heat and work is neglected. In addition EE do not define in advance the control volume boundary for the whole system, so that the results obtained by different studies often cannot be compared.

The EMergy Analysis (EMA) (Odum, 2000; Brown and Herendeen, 1996) may be regarded as a similar approach, based on the energy evaluation of flows. Differently from EE, EMA introduces a standard for the origin of all production chains and for the limits of indirect energy supply: it prescribes that all energy inputs to the analyzed process have to be evaluated in terms of the solar energy that has been historically necessary for making available each of them. This can be a very difficult task indeed, and in most real-world cases, a substantial number of (rather arbitrary) assumptions have to be introduced in order of performing the analysis, which implies that the numerical results ought to be regarded as affected by a potentially relevant - and often irresolvable - degree of uncertainty. An additional difference consists in the fact that in the EE, the embodied energy allocation in case of bifurcations is supposed to be proportional to the energy or material content of each bifurcating flow, while the EMA introduces a peculiar set of rules, defined by a specific Emergy Algebra (Odum, 2000) that prevents the Emergy budgets from being conservative. Although the Emergy Algebra is not devoid of a rational basis, its dogmatic application may result in some inconsistency, where technological and biological systems interact with each other (Sciubba, 2009; Reini and Valero, 2002; Gaggioli and Reini, 2014).

A wide group of methodologies aims to overcome the issue of the *qualitative* difference between the various forms of energy by using exergy for evaluating all energy and material flows. An almost complete review of those methodologies is beyond the scope of this paper and can be found in Rocco et al., (2014). In that paper, exergy based accounting methods are divided into two groups:

i. Monetary cost approach, using the monetary costs of Fuels *F* and fixed capital *Z* in order of consistently evaluate different production factors,
ii. Resource cost approach, using some assumptions in order of converting all fixed capital flows into exergy cost flows.

It is also highlighted that the first group (Rodríguez and Gaggioli, 1980; Valero et al., 1986; Tsatsaronis et al., 1993) assigns a unit cost equal to zero to natural resources as they are directly taken from the environment (crude) as well as to other externalities, like environmental pollution without remediation, therefore such a possible consequence of production may be regarded as a natural way for reducing the unit exergy cost of the products. On the other hand, the second group (Szargut, 1995; Sciubba, 2004) has to introduce some assumptions in order of converting all externalities into exergy cost flows; for instance in Szargut (1995) the unit exergy cost of human labor is assumed to be zero, or in Sciubba (2004) a fixed ratio is supposed to exist between monetary and exergy flows, in a defined economic context. The issue of incorporating human labor into exergy analysis has been recently addressed in Rocco, E. Colombo (2016), in the framework of the input-output economic analysis.

Not only in the ambit of EE, but also apting the exergy based costing, various approaches do not define in advance the control volume boundary for the whole system, but let the analyst free of fixing the limits of the considered production process, on conditions that a monetary, or a resource cost were defined for each flow crossing those limits.

3. Thermoeconomic Environment

To overcome difficulties related to control volume boundary and to allow the option of incorporating human labor and capital services into the exergy based TOP, the idea of a Thermoeconomic Environment (TE) is introduced in this paper. In fact, it is straightforward to think that a generic real energy system does not operate in an empty space but that it is surrounded by a biosphere (or an anthroposphere), where different kinds of resources are available at unit exergy costs greater than zero and with different constraints about their availability in time and space. This way of thinking may be regarded as *the system in its thermoeconomic environment*.

More precisely, the reference TE, may be defined as a set of *reservoirs*, where different kind of natural resources are *confined*; all reservoirs are surrounded by the zero-exergy matrix, which plays the role of the *dead state* for calculating the exergy of all flows inside the energy systems, as well as of all reservoirs. The zero-exergy matrix can be defined as the *dead state* model proposed in Gaggioli and Petit (1977) or in Rodríguez and Gaggioli (1980). It is worth noting that the confined condition of natural resource *reservoirs* is crucial: if the constraints that allow the confined condition of a particular resource are destroyed, the resources compound is mixed with the zero-exergy matrix and some irreversible processes consume the exergy previously contained in the reservoir, reaching the thermodynamic equilibrium.

Notice that the idea of the TE, made by a zero-exergy matrix that embeds a set of reservoirs can be also useful for other purposes than the representation of natural not-renewable energy and material resources. For instance, the concept may be used to define an internal dynamics of the natural environment, or for representing the sequestration of a specific type of waste from the production process (at present, this is one of the most popular options for mitigating the CO_2 accumulation in the atmosphere), or finally for introducing into the analysis some kind of special products, that must be employed in a particular site, or a specific time, very far from the place or the instant in which it has been produced, like – for instance – what happens for the monetary capital. Notice indeed that the TE is not too big to be modified by the considered production process, because the amount of exergy in each reservoir is limited and, in principle, it can be sensibly reduced by the consumption of the production processes; moreover, also the zero-exergy matrix may change its temperature $T°$ (Reini and Casisi, 2016) and its composition in consequence of its internal dynamics (for instance the periodic oscillations of the availability of solar energy) or in consequence of the interaction with the global energy system. This could be regarded as a drawback, in view of a precise and unquestionable calculation of the exergy of all flows, but is crucial in the exergy cost evaluation of the residue flows of the production processes, as will be discussed in the following.

3. Global Energy System

The Global Energy System (GES) may be regarded as the considered production system, plus the TE, plus all exergy streams and energy conversion processes connecting the considered production system to the TE, making available all Fuels F and fixed capital Z required, directly or indirectly, by the production system itself.

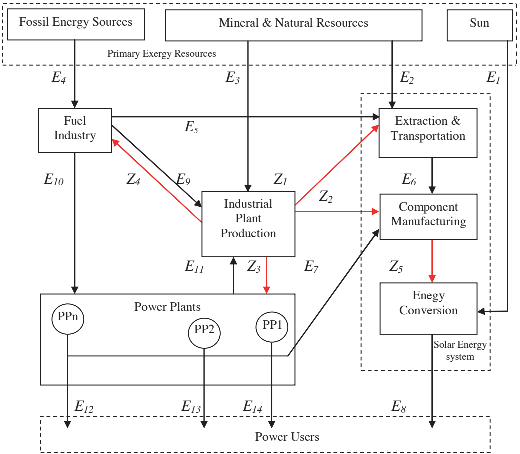

Fig. 1: The GES for a solar energy production system.

In Fig.1 a solar system is considered as an example, made up of three sub-systems, (it is highlighted inside the central dashed rectangle). Natural resources from the TE (E_2) are used, after extraction and transportation (E_6), for manufacturing a solar energy conversion system; than it is used for converting the solar radiation (E_1) into electric power (E_8). Besides the solar energy conversion system and the TE, the GES includes three big sub-systems only: the *fuel industry*, supplying fossil fuel (E_5) for extraction and transportation of row mineral resources, for the industrial plant production (E_9) and for the power plants operation (E_{10}); a set of *power plants*, supplying electric energy to all power users (E_7 and E_{11}-E_{14}) and the *industrial plant production*, supplying all fixed capital required by the other productive phases (Z_1-Z_4), except the fixed capital required by the manufacturing of the solar energy conversion system (Z_5), which is produced inside the control volume of the solar system itself. Notice that the exergy equivalent of money can be calculated from the cost balance of the *industrial plant production*, starting from the monetary flows [€/s] balance, calculated on the same time basis of the exergy flows.

4. Constructal Law

The GES is than a network of flows, where *different* irreversible processes interact in order of extracting exergy from the TE, obtaining one concentrated product flow in a defined site of the network. Therefore, the CL is expected to hold for this kind of system as well as it is used in literature to predict the shape and structure for a lot of physical flow systems (Bejan and Lorente, 2013). The Product flow may be the electric power produced by the solar energy system in Fig. 1, as well as some kind of food, or simply the living biomass of a certain species in a defined ecosystem. As it is well known, the CL, proposed by Bejan in 1996, states:

> *For a finite-size flow system to persist in time (to live), its configuration must evolve in such a way that provides greater and greater access to the currents that flow through it.*

If the *current that flow through* the energy system is identified with its product flow, the CL prescribes an evolution toward a production increase. In the GES, the exergy flows are not regarded as physical streams that flow in a real space, but rather as the functional relations among components, in the abstract space of possible productive interconnections, that make up the so called *Productive Structure* of the GES. In spite of these differences, Constructal Theory and TOP have also some similarities. For instance, they both pursue the optimal allocation of two different types of losses: high permeability vs. low permeability flow losses in the Constructal Theory, while local losses inside the process vs. external losses for making available all resources actually consumed, at local level, by a component or a process in the TOP. The expectation is that the CL could show us which productive structure have to be selected for persisting, during the evolution of the energy system, and which other have to be selected for the extinction, as well as the Second Law tells us that high entropy configurations are very likely to appear, when a system is approaching the thermodynamic equilibrium.

5. Unit Exergy Cost reduction principle

In the ECT, the direct and indirect consumption of exergy resources for obtaining a required product P is named the *exergy cost* of *P* and consequently the ratio between the exergy cost and *P* is named its *unit exergy cost* (k^*_P). In that approach the limits of the control volume are not prescribed by the theory but they are chosen by the analyst. This source of uncertainty can be overcome if we prescribe that all direct and indirect consumptions have to be tracked back to the TE, previously introduced. Let's name F_{TE} the sum of all direct and indirect Fuels received by the TE. The previous definitions can be summarized in Eq. 1):

$$F_{TE} = P\, k^*_P \quad 1)$$

Therefore, the production increase prescribed by the CL can be expressed as Eq. 2):

$$\delta P = (\delta F_{TE}\, k^*_P - F_{TE}\, \delta k^*_P) / (k^*_P)^2 > 0 \quad 2)$$

Whilst F_{TE} and k^*_P are necessarily positive quantities, the sign of δF_{TE} depends on the behavior in time of the exploitation of resources from the TE. We can easily identify two main kinds of behaviors:

a) *Hubbert like*, where a starting phase, characterized by an exponential (Malthusian) growth, is followed by a maximum (the *Hubbert* peak) and than by a declining phase, where δF_{TE} is negative.
b) *Sigma like*, where the exponential starting phase is followed by a flex and then by an approximately constant value (asymptotically approached), where δF_{TE} is close to zero.

The first kind is characteristic of not-renewable resources, like fossil fuels, whilst the second one is characteristic of renewable resources, like solar energy. It is worth noting that both the Hubbert peak and the asymptotic value, in the first and second case, respectively, may depend on the technological development of the production system, or on the evolution stage of the ecosystem. An example of the last case can be found in Falkowski (1997), which can be regarded also as a demonstration that biological energy systems do modify the zero-exergy matrix of the TE!

In both cases a) and b), if the unrestricted availability of resources is over (i.e. when the *finite size* of the flow system is playing a crucial role) Eq. 3) may be assumed:

$$\delta F_{TE} \leq 0 \qquad 3)$$

By combining Equations 2) and 3) it can be easily inferred that the variation of the unit exergy cost k^*_P has to be strictly negative:

$$\delta k^*_P < 0 \qquad 4)$$

In other words, the CL prescribes an evolution toward a reduction of the unit exergy cost of the product. Therefore, the last has no more to be regarded as an axiom of TOP, but as a consequence of a physical principle that tells us which energy systems can persist in time (to survive) and which others would be selected for extinction.

6. The arising of recycling

The reduction of the unit exergy cost of the product can be looked for basically in two ways: i) by improving the exergy efficiency inside the considered process (i.e. by reducing its specific exergy consumptions); ii) by identifying, inside the GES, an available flow of the same nature of a fuel of the considered process, but with a lower unit exergy cost with respect of fuel actually consumed, and then by *modifying* the productive structure of the GES, in order of replacing the latter with the former.

To show this kind of evolution, consistent with the Construcal Law, let's assume that the TE and the whole GES outside the solar system in Fig. 1 does not vary, whilst the solar system can modify the fixed capital (Z_2) and the electric power (E_7) required by the manufacturing of the energy conversion components. As is usual in the ambit of thermoeconomics (see, for instance, Tsatsaronis, 2011) a trade-off is introduced between the *capital intensity* (Z_2/E_6) and the *energy intensity* (E_7/E_6) of the production process, at constant energy conversion efficiency (E_8/E_1) of the solar system energy conversion phase. A possible technological development (or improved energy conversion strategy) may be also taken into account, by introducing the hypothesis that a similar trade-off exists also at energy conversion efficiencies higher than the reference one, impling a higher consumption of local resources (capital, or exergy). Reini (2016) showed that, with these reasonable hypotheses on the fixed capital (Z_2), an evolution is always possible toward a lower unit exergy cost of the Product E_8, consistently with the Construcal Law and the TOP. If this improvement may go on enough, a condition is reached where $k^*_7 = k^*_8$. At that point, there are two option for obtaining the electric power required by the component manufacturing phase, at the same unit exergy cost: using the product of the power plant considered along with the previous evolution, or *split the product* E_8 of the solar energy system itself in two flows, the first one for the power users and *recycling back* the second one, in order of replacing the previous external flow E_7. In this second option, a recycling flow arises in the productive structure, in consequence of the evolution prescribed by the CL.

7. Disposal of residues in the Thermoeconomic Environment

All GESs include some flows which are obtained during the production process but which are not products and then the system has to dispose them off (see, for instance, Liao et al., 2012). They are named residues and sub-products and the problem of their thermoeconomic evaluation is discussed in Reini and Valero (2002) and in Torres et al. (2008). A different approach is suggested here, consistently with the CL and taking advantage by the definition of the TE. Three main options can be identified for the disposal of residues:

1) Disposing them off *directly* in the TE, without any kind of additional operation.
2) *Neutralizing* them; this option necessarily requires additional fuels and/or additional fixed capital (natural or artificial), in order of reducing the residues flows to an exergy level close to the zero-exergy matrix of the TE, or in order of creating a new confined reservoir inside the TE.
3) *Converting* them as input of some new process, which is able of obtaining any useful product.

The first option might be regarded as the most favorable, in view of the previous considerations about the unit exergy cost reduction principle. In fact, both second and third options imply an additional charge of resource consumption on the original system, in order of obtaining the product *P*. But this is true only if the disposal of residues do *not affect* the exergy stock in the TE. Keeping in mind that the TE is not unmodifiable in the resent approach, its exergy stock can be reduced in two ways:

a) *Modifying* the zero-exergy matrix temperature ($T°$) or composition, so that a part of the reservoirs has its exergy content reduced;
b) *Damaging* the constraints that allow one or more reservoirs (including fresh water, fertile soil, ecc.) to persist in their confined condition.

If the disposal of residues do *affect* the exergy stock in one way, it has an exergy cost, which, in principle, may be very high, even if not easy to be evaluated. This cost has to be charged on the original system, so that the consequence of disposing directly the residues in the TE is an increase of the unit exergy cost of the product, i.e. the opposite of what prescribed by the TOP and the CL. On the contrary, the third disposal option is possibly the most favorable, because in this case the product *P* is discharged of some resource consumption, so that its unit exergy cost can decrease (Reini and Valero, 2002; Torres et al., 2008).

8. Conclusions

In the paper the concept of Thermoeconomic Environment has been introduced, and the possible application of the Constructal Theory to the evolution of the productive structure of any energy system (natural or artificial) has been discussed.

This approach allows obtaining that the CL prescribes an evolution toward a reduction of the unit exergy cost of the product. Therefore, the last has no more to be regarded as an axiom of TOP, but as a consequence of a physical principle that tells us which energy systems can persist in time (to survive) and which others would be selected for extinction. In consequence of the evolution prescribed by the CL recycling flows may arise in the productive structure and, once a recycling flow has arisen, the selection criteria expressed by the CL works in the direction of reinforcing the recycling flow itself. Furthermore, residues and sub-products cannot be indefinitely accumulated but they have to be generally converted into some kind of product by different (new) production processes, supporting the parading of the *Circular Economy*. In the outlined context, the evolution of energy systems toward highly interrelated productive structures, with multiple recycling flows, can be generally regarded as a consequence of the CL.

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Complex source components assessment: Criteria for 3D air emission monitoring in the case of an urban port area, Naples (S Italy)

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Abstract

Urban population wellbeing is strictly connected with a sustainable lifestyle, supported by a proper use of environmental and economic resources, integrated with an adequate social 'dimension' quality. This ideal picture is contrasted by the real one, as demonstrated by a huge amount of researches. The first step toward the minimization of the existing environmental impacts is associated with the assessment of the existing potential threats. Nonetheless, this option is difficult due to the fact that urban areas can be considered mainly as black boxes with respect to emissions. Moreover, as confirmed also by preliminary data, multiple and non-punctual sources exist which have non-uniform intensities, spatial and temporal distributions.

Consequently, the purpose of this work is to define a set of effective criteria for developing a 3D environmental scenario analysis. The port of Naples (S Italy), surrounded by the city of Naples itself, was chosen as a case study. The basis for defining the given criteria are the identification of sources, trajectories and targets of emissions. The instrumental approach to such a scenario analysis, which hierarchically involves the use of different remote/proximal sensing technologies (such as satellites and UAV/drones as platforms, together with advanced sensors), is discussed. Finally, this preliminary study unveils the potentiality of such an approach as a first component for local environmental management systems, which can support the development of appropriate actions and urban policies.

1. Introduction

Urban population well-being and sustainable lifestyle is presently an ideal goal, which contrasts with what we know about the urban environment. In fact, so many times the available scientific literature shows different representation of unhealthy, socially unequal and polluted environments, whose growth requires and will require well-defined and planned political roadmaps, as well as incisive actions to improve urban environmental and human life quality.

Intense external resources exploitation and anthropogenic activities continuously increase both the environmental footprint and the risks related to the interaction with potentially harmful emissions. The impact of atmospheric pollutants, both in form of gaseous compounds and atmospheric particles, is well-assessed in the literature. In particular, the role of NO_x in the formation of secondary aerosol particles is known (e.g.: Casazza, 2015), as well the adverse impact of PM on human health (e.g.: Romanazzi et al., 2014; Casazza, 2015; Casazza et al., 2016). Thus, being the effects of poor air quality on human and ecosystem health known, a great attention is still payed to understanding, measuring and modelling urban atmospheric air pollution and its diffusion to larger scales. However, due to the scenario complexity – i.e.: extended and variable emission sources, variable atmospheric dynamics, complex terrain and 3D nature of urban environment, together with the intrinsic variability of human behaviors – it is difficult to overcome the imagine of a city as a black-box.

Several tools now support the representation of air quality status, as well as the evolution of urban air pollution, potentially enabling the end-users to improve the present difficulties. In particular, the efficacy and efficiency of GIS use is now widely recognized by the scientific literature for this purpose (e.g.: Tang et al., 2013; Sáňka et al., 2014; Kanakiya et al., 2015; Réquia Júnior et al., 2015; Zou et al., 2015; Liu et al., 2016a). Nonetheless, the desired future development of GIS would require also a switch to knowledge of the atmospheric conditions (Kumar et al., 2015a). Moreover, interpolators are often needed both to predict air quality in unsampled locations and to assign personal exposures, while a measure of the spatial uncertainty should be also incorporated in the data outcomes evaluation (Ribeiro et al., 2016). On the other side, air quality forecasts can be suitable, thanks to the development of products, derived from well-renowned models, such as Weather Research and Forecasting Model (WRF), in its WRF-Chem version (e.g.: Ritter et al., 2013; Cui et al., 2015; José et al., 2015; de la Paz et al., 2016; Liu et al., 2016b). In fact, WRF-Chem shows an overall good performance for most meteorological and chemical variables on a decadal scale (Yahya et al., 2017). However, on smaller time scales and considering the need of a high spatial resolution, difficulties are still encountered to resolve both the horizontal and the vertical resolutions (e.g.: Scarino et al., 2014; Oda et al., 2017). These deficiencies, apart from the ones intrinsically connected with WRF model present weaknesses, are partially due to missing input data and their low spatial resolution (Kuik et al., 2016).

This is why the first and crucial point of the chain, which starts from the input data into representation and, then, into information useful for policy-making and urban administrators, is constituted by measuring technologies, their network and the methodology for collecting the necessary data. This is particularly true, if we are willing to discriminate hotspots within a city. Thus, the purpose of this paper is to define a set of effective criteria for developing a 3D environmental scenario monitoring approach, as a preliminary methodological basis for a future monitoring activity, which is planned for the port of Naples. The basis for defining the given criteria are related with the intermediate purpose of such an activity: the identification of sources, trajectories and targets of emissions, being the environmental management of the same area the final purpose of this work. The instrumental approach to such a scenario analysis, which hierarchically involves the use of different remote/proximal sensing technologies (such as satellites and UAV/drones as platforms, together with advanced sensors), is discussed. Finally, the conclusions, as well as research and actions future perspectives, are defined.

2. Methodological approach

This paper provides a literature review about the methods, technologies and tools, which can be applied to monitor the main atmospheric pollutants concentration trends in the specific case of a hotspot embedded into a complex source (i.e.: the urban environment). Our case study, in particular, is focused on the port of Naples (S Italy).

Figure 1. The location of the port of Naples (S Italy)

The Port of Naples (Figure 1) is one of the largest Italian seaports and one of the largest seaports in the Mediterranean Sea basin having an annual traffic capacity of around 25 million tons of cargo and 500,000 TEU's. The port is also an important employer in the area, having more than 4,800 employees, that provide services to more than 64,000 ships every year.

A general discussion about port emissions, related both to shipping and to land transport and to port management activities is omitted here for sake of brevity.

3. Results and discussion

High spatio-temporal resolution urban air pollution maps derived from the development of adequate measuring networks are discussed in the scientific literature (e.g.: Kanhere, 2013; Steinle et al., 2013; Hasenfratz et al. 2014; Castell et al., 2015). With respect to used instruments, the rise of low-cost sensing is giving a new impulse to the development of monitoring activities (e.g.: De Nazelle et al., 2013; Kumar et al., 2015b; Snik et al., 2015; Jerrett et al., 2017). These newly developed technologies can be well-integrated with the existing compact ones, displaying the capability of detecting pollutants with high temporal resolution (e.g.: Casazza and Piano, 2003; Tsujita et al., 2005; Mead et al., 2013; Petäjä et al., 2013). Due to the 3D nature of urban environment and considering that the urban exposed population lives also inside vertically-developed buildings, the use of sensors, capable to discriminate this spatial dimension, becomes important. Relatively compact instruments already exist, such as mini-LIDAR and compact DOAS (e.g.: Mejía et al., 2013; Arellano et al., 2016; Chazette, 2016). All these data outputs can be integrated with existing monitoring networks or traditional instruments to assess also the chemical nature and long term trends of air pollution (e.g.: Casazza et al., 2013; Malandino et al., 2016). Moreover, the use of proximal and remote sensing from aerial and satellite platforms can further enhance this process (e.g.: Lega and Napoli, 2008; Nguyen et al., 2010a, b; Persechino et al., 2010; Lega and Persechino, 2014; Lega et al., 2014; Errico et al., 2015; Lin et al., 2015). Other mobile platforms can also be used for mounting and operating surface measuring instruments (e.g.: Van den Bossche et al., 2015; Apte et al., 2017). Finally, the methodology for setup and data processing have to be considered too (Van Poppel et al., 2013; Levy et al., 2014).

The port area, in the case of Naples (S Italy), represents a complex source, where different activities occur. Consequently, different atmospheric pollutants are potentially released into the atmosphere with a variable intensity and spatio-temporal distribution. Moreover, the port is located within the metropolitan area, close to the downtown, which represents a different complex source of atmospheric emissions. A set of questions need to be preliminary addressed. In particular: how to define the 3D atmospheric boundaries of the port with respect to the city? Are there any specific port 'signatures', which can be detected with compact and ready-to-use instruments? How to represent the data? How to transform the data into useful information?

The first question was partially addressed in a recent work by Casazza et al. (2017), where a preliminary survey is also recommended, recalling the indications given by EPA (1992), where the concepts of emission zone of influence (referred to a given emitter, as the distance from that specific source, which contributes no more than 10% of the measured PM concentration), spatial uniformity (i.e.: the extent to which particle concentrations vary over a specified area) and spatial coefficient of variation (i.e.: the deviation of measurements taken by a single sampler from the spatial average of all samplers) were introduced. A general criterion for locating a network of measuring instruments, which is valid for all the pollutants, independently from their nature, is to place the monitoring devices within distances, which correspond to an expected concentration level change exceeding 20%, calculated either from dispersion models (whenever minimum required meteorological and emission data are available) or from screening studies (Schwela, 2010). Other general criteria are detailed in another document by EPA (2013). While planar monitoring characteristics at surface level are well defined, also a vertical dimension needs to be introduced. It is obvious, in fact, that atmospheric pollutants are diffused into a volume. Moreover, considering the vertical dimension of urban centers, it is important to consider that the target (i.e.: the population, exposed to potentially toxic substances) is distributed over the three spatial coordinates, living a great part of the day indoor, as usual for cities. We will not recall here the huge body of literature on outdoor air quality influence on indoor environment. One of the most meaningful parameters is the height of the mixing layer, since it is related to the possibility for any pollutant to be vertically distributed from a source. This can be represented locally through the Monin–Obukhov length, which is used in determining the height of the Atmospheric Boundary Layer (ABL) and also as input for dispersion models for industrial source applications (e.g.: Sugiyama and Nasstrom, 1999; Cimorelli et al., 2005).

Portable, low-cost PM sensors, such as the PMR Drone – Particle Monitoring Recorder or the DustTrak (From TSI) can be used to provide valuable real time information on air quality and emission sources. However, these sensors need careful evaluation against more standard methods. In a comparison of the DustTrak with standard EPA approved methods, Jaffe et al (2014) found nearly a factor of two difference. After correcting the data, these authors found that the DustTrak could give reliable data that was comparable with EPA methodologies. In addition, some lower cost sensors may have greater noisier signals, making interpretation somewhat more complex. These factors must be considered in designing a system for their use and portable sensors must be well characterized against reference methods prior to spatial sampling.

Nonetheless, portable sensors can give valuable information compared to fixed monitors. One possibility is to do daily sampling on a fixed route around the city and port that would provide data across a range of meteorological conditions. Maps of this data would then give information on significant sources for all meteorological conditions. These could also be used to compare against high resolution Eulerian modeling (e.g. WRF at 1 km resolution or finer). Vertical profiling, as with a drone, could also provide critical boundary layer height information, that could be used both to drive statistical relationships and to evaluate model forecasts. Here again, regular drone sampling at fixed locations would provide key information on the vertical distribution, but also statistical variations that are key for understanding the source-receptor relationship.

Diesel engine sources can be characterized by emissions of soot or black carbon (BC). Here too, a portable sensor is available (e.g. the microAeth®/MA300, See: https://aethlabs.com/) that measures black carbon in real time with one minute or better time resolution. Combined with the PM measurements, the BC/PM ratio could be used to discern diesel emissions from other sources (e.g. gasoline powered vehicles).

Finally, all of these observations could be combined into an analytical GIS platform, such as Google Earth or ArcGIS. Satellite observations and their derived products from the NASA MODIS instruments (https://modis.gsfc.nasa.gov/) can then be easily imported into either framework. This allows for detailed comparisons of the higher resolution in-situ observations with the satellite data.

4. Conclusions

This paper reviews the methodological approach for monitoring an extended source (i.e.: the port of Naples) embedded into another extended source (i.e.: the urban environment of Naples). The criteria for a monitoring approach are not limited to a planar view, as usually done, but introduce also the vertical dimension, since pollutants are also diffused vertically in the atmosphere. Moreover, also the population exposition to the atmospheric potential toxicants is distributed along the three spatial dimensions. This is why a 3D approach is needed. The available technological options for measuring the different pollutants, as well as the data output integration into available information systems (such as GIS-based tools) is described.

This work will constitute the basis for a future monitoring activity, which is planned to identify and mitigate the adverse impacts of the port emissions, while preserving its economic and social values, which constitute, both historically and at the present time, an important characteristic for the area of Naples.

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A reflection about Emergy Analysis of Agricultural Systems by focusing on the Agro ecological Transition Process.

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1. Abstract

Small ecological family farms in Brazil bring benefits to the ecosystem and society in which they are inserted; these benefits can be measured in terms of emergy and social indices. Taking this factors in consideration, emergy accounting needs some improvements.

2. Introduction

The rural system studied underwent a radical evolution in the last ten years. That was possible due to the access to the practices of an agro ecological system in the neighborhood.

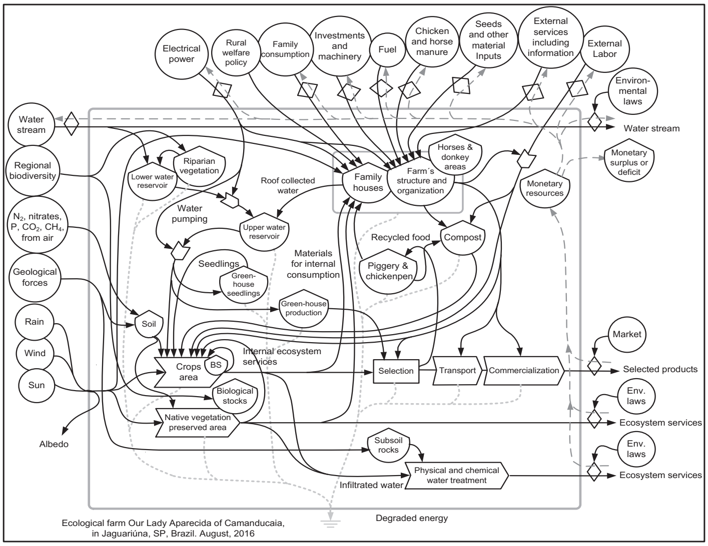

Fig. 1: Diagram of “Aparecida do Camanducaia” Farm

3. Methods

The farm has 14,5ha and a complex structure. 8ha are dedicated to grow more than 50 fruits and vegetables. Three families live there and eight family members work on production.

4. Results

Present time indicators were compared with those of twenty years ago, when they produced agrochemical oranges: lower transformity (179.126 vs 2.988.272 sej/J), higher renewability (73% vs 25%), higher emergy yield (1.21 vs 1.07), lower emergy investment (4,73 vs 13,92), lower environmental load (0,56 vs 1,66), better emergy exchange (0,36 vs 2,93), higher population density (0.90 vs 0.21 people/ha).

5. Discussion

A key point was the incorporation trade which promote a better profit margin, using the good quality information acquired from a neighbor (Eco Vila Yamaguishi). The methodology improvements allowed a better assessment, basically we assumed the renewability fraction of inputs in the calculation of Ren [Y_R/Y], EIR [F/R] and EYR [(R/F) + 1].

Prospective LCA of the production and EoL recycling of a novel type of Li-ion battery for electric vehicles

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Abstract

The transport sector as a whole – and within it passenger cars in particular – are currently responsible for a large share of the total greenhouse gas emissions of many developed and developing countries, and a transition to electric vehicles (EVs) is often seen as a key stepping stone towards the de-carbonization of personal mobility. Research is on-going in the continuous development and improvement of lithium ion (Li-ion) batteries, which may use a range of several different metals in conjunction with lithium itself, such as: lithium manganese oxide (LMO), lithium nickel cobalt manganese oxide (NCM), lithium iron phosphate (LFP), and others. Within the MARS-EV research project, a new cell chemistry has been developed and tested, using a lithium cobalt phosphate (LCP) cathode and graphite anode. This work presents the first life cycle assessment (LCA) for such LCP batteries, as well as of a newly-developed wet battery recycling process which is less energy intensive than alternative pyro metallurgical processes, and enables the recovery of not only the valuable metals, but also of the graphite component, thereby avoiding the associated CO_2 emissions.

1. Introduction

The automotive sector is gradually embracing electric power trains in replacement of the internal combustion engines (ICEs) that have heretofore been the *de facto* standard. This move is intended primarily as a means to significantly curb the levels of airborne pollutants in densely populated areas such as cities and towns, with the additional side benefits of potentially reducing the vehicles' life-cycle cumulative energy demand and greenhouse gas emissions too. However, while the reductions in polluting emissions during the use phase are automatically achieved by all electric vehicles (EVs), the latter's comparative environmental and energy performance on the full life cycle scale *vs*. that of conventional ICE vehicles ultimately depends on two critical factors: (i) the way in which the electricity that powers the vehicles is generated, and (ii) the indirect energy and emissions that are 'embodied' in the large and heavy battery packs that are used to store that energy. In this paper, we address the latter question, by presenting a prospective life cycle assessment (LCA) of the production and end-of-life (EoL) recycling of a novel type of lithium-ion (Li-ion) batteries for EVs, and discussing the results within the context of a range of previously available alternatives.

2. Materials and methods

As illustrated in Figure 1, the analysed system consists of all the manufacturing steps that lead to a complete 17kWh battery pack (total mass = 108 kg) to be used in compact EVs ('cradle-to-gate' boundary), plus the optional inclusion of a novel EoL treatment aimed at achieving high recycling rates and the corresponding energy and emission credits ('cradle-to-gate' + End-of-Life boundary). On the other hand, given that the focus of this study is specifically on the energy and greenhouse gas emissions that are 'embodied' in the batteries, the use phase (which strongly depends on the assumed driving cycle and on the grid mix that supplies the electricity for re-charging) has been deliberately omitted.

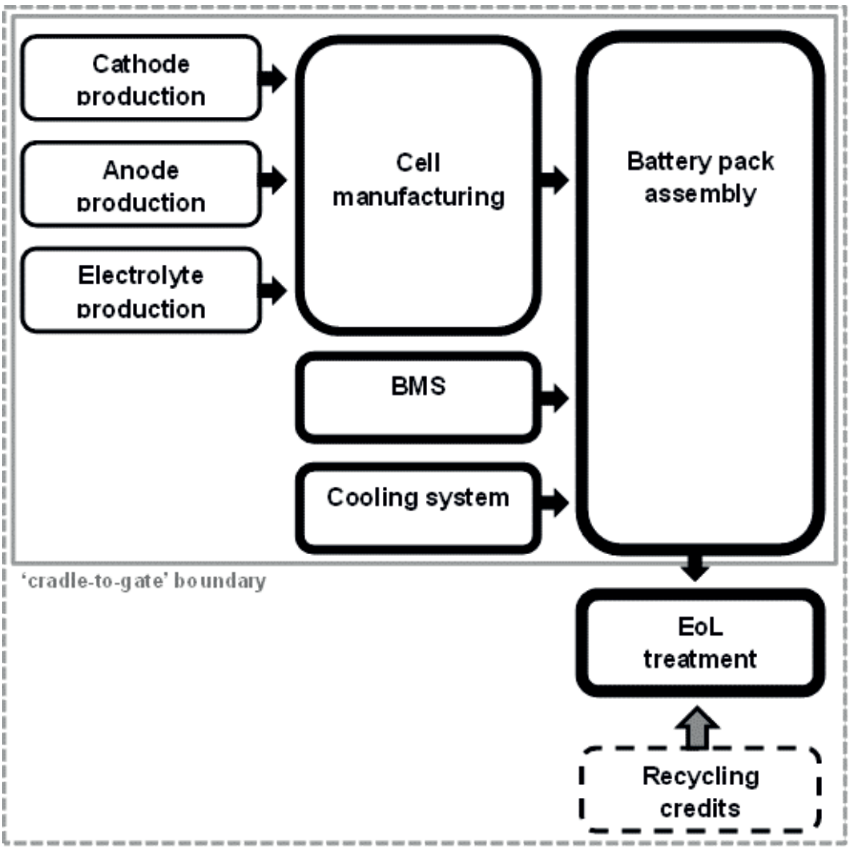

Figure 1 – Flow diagram of the main steps in the manufacturing of a complete Li-ion battery pack, with indication of optional end-of-life (EoL) treatment and associated recycling credits.

The chemistry of the electroactive components of the battery cells was informed by the research carried out within the EU FP-7 research project 'MARS-EV'[1]. In particular, the composition of the cathode is what is most responsible for setting apart this battery type from those previously employed and analysed to date: instead of the more common lithium manganese oxide (LMO = $LiMn_2O_4$), lithium nickel-cobalt-manganese oxide (NCM = $LiNi_xCo_yMn_zO_2$), or lithium iron phosphate (LFP = $LiFePO_4$), this new cathode utilizes lithium cobalt phosphate (LCP = $LiCoPO_4$) as the key electroactive material.

[1] http://www.mars-ev.eu

Given the novelty of this material, the only information available on its production process referred to a pilot-scale batch. While this was considered to be still adequately representative of the intrinsic demands for the main technology-specific material inputs (including the key lithium and cobalt precursors), the reported values for the compressed oxygen and, importantly, electricity inputs appeared to be much larger than the corresponding inputs for the production of the more common LMO chemistry as reported in the literature[2]. This raised an issue in terms of the subsequent comparability of the results of this analysis to those from previous studies that refer to commercial scale production. Conservative estimates equal to twice the oxygen and electricity input values that are reported in the Ecoinvent LCA database for LMO production were therefore adopted here as probable better proxies for LCP production too, assuming further expansion of the latter to full commercial scale in the near future.

The electrochemistry of the battery cells is then completed by a graphite anode and a lithium-rich electrolyte in a blend of organic solvents, and the individual cells are isolated using a novel cellulose-based packaging material (all the relative foreground inventories were supplied by MARS-EV project partners, and integrated wherever needed on the basis of the appropriate upstream chemical reaction stoichiometry).

Finally, ninety-six battery cells are assumed to be assembled into four modules that together comprise a battery pack, and the latter is complemented by the necessary electronics (the 'battery management system' – BMS) and a suitable cooling system. The bill of materials for the manufacturing steps beyond the battery cell stage were informed by the BatPaC software developed by Argonne National Laboratory[3], while all electricity inputs for all production stages were modelled according to the current average ENTSOE (formerly UCTE) European grid mix.

The novel EoL treatment process developed within the project and analysed here consists of three daisy-chained steps: (1) manual electrical control, discharge and dismantling; (2) dry mechanical shredding and grinding; (3) wet chemical treatment. Details of the critical wet processing step cannot be disclosed due to confidentiality agreements, but all necessary inputs and resulting emissions have been included in the LCA. The key advantages of this new EoL treatment, with respect to previously developed pyro-metallurgical alternatives[4,5,6], are the lower energy consumption and the ability to recover not only the valuable metals (90% recovery rates for aluminium, copper, lithium and cobalt), but also of the graphite component (90% recovery as black carbon cake), thereby avoiding the associated foreground CO_2 emissions.

From a methodological perspective, energy and emission credits were assigned to the recovered metals according to a substitution logic, i.e.: the Al and Cu recovered in steps 1 and 2 were assumed to displace the respective current primary/secondary market mixes for those metals, while all the metals recovered in step 3 were assumed to displace the most common respective salts, with all stoichiometries duly adjusted.

3. Results

Figure 2 illustrates the cumulative energy demand of the analysed battery pack (expressed in terms of MJ of total primary energy input per kWh of battery energy capacity).

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[2] http://www.ecoinvent.org/database/ecoinvent-33/ecoinvent-33.html
[3] http://www.cse.anl.gov/batpac/
[4] http://pmr.umicore.com/en/batteries/our-recycling-process
[5] http://www.sumitomocorp.co.jp/
[6] http://www.glencorerecycling.com

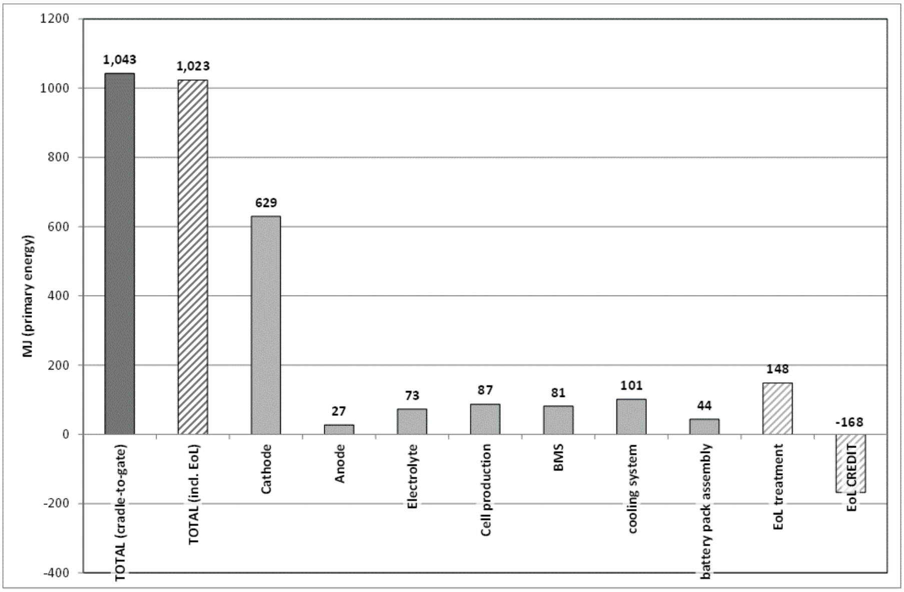

Figure 2 – Cumulative energy demand (CED) per kWh of battery energy capacity, with and without end-of-life (EoL), and highlighting the individual contributions of the main components.

As clearly visible, the largest contributor by far (> 60%) to the CED of the entire battery pack was found to be the cathode. Interestingly, this result is largely determined by the 'embodied' energy in the input materials for the cathode (the latter being informed by direct pilot-scale measurements, and only marginally susceptible to further reduction), whereas the direct manufacturing energy input (which was estimated on the basis of literature information on large-scale LMO cathode production) is comparatively unimportant.

Also noteworthy is the fact that the inclusion of the EoL treatment steps and associated credits only leads to a marginal reduction of the total CED (-2%).

Figure 3 then illustrates the cumulative greenhouse gas (GHG) emissions of the analysed battery pack (expressed in terms of kg of CO_2-equivalents per kWh of battery energy capacity).

Here too the cathode stands out as the largest contributor to the overall result, and in fact, its relative share is even higher (~70% of the 'cradle-to-gate' total), due to comparatively large foreground CO_2 emissions resulting from the chemistry of the cathode production process.

When it comes to the EoL, though, the emission credits afforded by the recovery of the valuable metals (all of which are carbon-intensive to produce) lead to a larger relative reduction (-8%) of the total impact in this category.

Finally, Figure 4 illustrates a comparison of our findings to those published in the recent (post-2010) literature for similarly complete 'cradle-to-gate' analyses of commercial battery packs based on the three most common Li-ion chemistries (LMO, NCM and LFP). Due to limitations in some of the referenced studies, such comparison is limited here to the discussion of the GHG emission results.

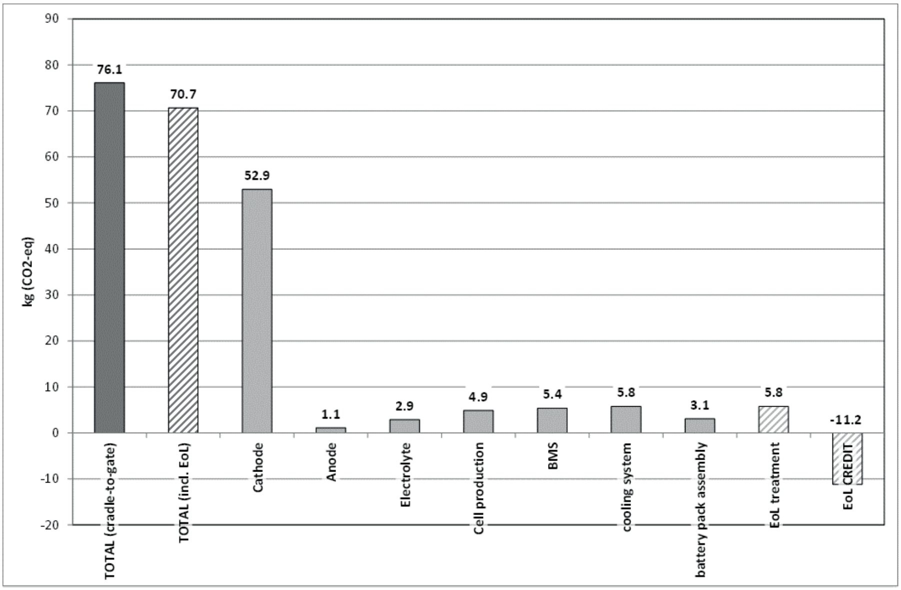

Figure 3 – Cumulative greenhouse gas (GHG) emissions per kWh of battery energy capacity, with and without end-of-life (EoL), and highlighting the individual contributions of the main components.

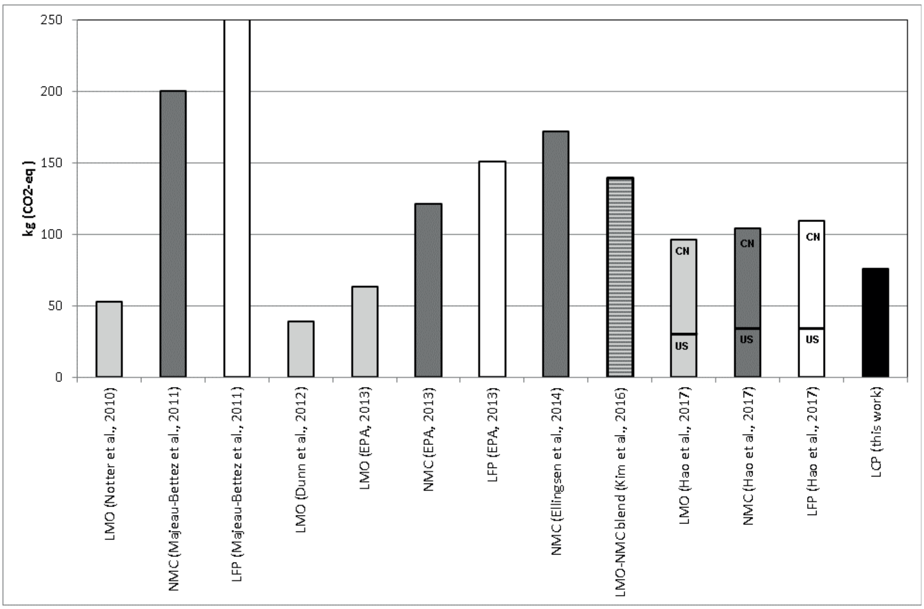

Figure 4 – Comparison of the reported cumulative greenhouse gas (GHG) emissions per kWh of battery energy capacity across selected published studies ('cradle-to-gate' boundary).

The first striking feature of this comparison is the sheer range spanned by the results. On closer inspection, this is due to a number of factors: first and foremost, there is intrinsic variability in the physical size and structure of the analysed battery packs, which leads to wide variations in the assumed relative mass shares of the non-electrochemical components (BMS, cooling system, exernal packaging, etc.), and therefore on the calculated impacts per kWh of battery energy capacity. Secondly, many of the authors had to rely on "expert estimates", "extrapolations based on R&D values", "top-down estimates", etc., which may have impacted the accuracy of their results. Also, given the demand for high-energy-intensive materials for the production of the cells, the assumed background electricity grid mix(es) and their associated carbon intensities have a potentially large effect on the final results, as evidenced by the range of values obtained by Hao et al. (2017) when alternatively assuming US or Chinese production.

Be that as it may, the cathode composition appears to have a distinctive effect on the outcome, as highlighted by the use of different shadings for the bars in the chart. Within each 'family' of cathode chemistries, there is some indication of a general downward trend with time (albeit within rather large confidence bands, because of the limitations discussed above, and with the possible exception of LMO batteries).

In light of all of the above, the results for the production of the LCP battery pack analysed here seem to be indicative of a solid performance in terms of total GHG emissions.

4. Conclusions

The LCA of a new type of Li-ion battery packs for EVs based on lithium cobalt phosphate (LCP) chemistry has led to promising results in terms of cumulative energy demand and greenhouse gas emissions. This analysis, and a comparison to previously published results, has also highlighted a number of lingering methodological issues in terms of how to address and resolve sources of uncertainty linked to battery pack standardization and extrapolation of laboratory and pilot plant inventory data to more meaningful commercial scale operations.

Finally, the performance of a new wet recycling process has also been assessed in a positive light, even though the total reductions in cumulative energy demand and GHG emissions, when also accounting for the credits afforded by EoL material recovery, remain relatively minor.

Acknowledgements

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Electric vehicles in the EU: between narrative and quantification

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Abstract

The EU transport sector is struggling to reach its renewable targets and remains the largest consumer of fuels across member states. Electric vehicles have been championed as a possible solution for multiple issues, from pollution in cities, to emissions, to energy security. Assessments of their performance have proven to be tricky, with large variety in results, partially due to the difficulty in assessing innovations. An alternative methodology, called Quantitative Story-Telling, is proposed, recognizing the role played by narratives both in the production of information and in shaping policies. Underlying narratives surrounding electric vehicles in EU documents are mapped across hierarchical levels, and their quality is checked by developing a scenario of 100% electric vehicles in urban centers, one of the goals of the EU's 2050 Transport Strategy. Preliminary results are presented focusing on three narratives identified in EU documents, mapping onto three core EU narrative domains: energy security, climate change and green growth. The quality of the three narratives associated with electric vehicles, namely that they can reduce imports, reduce emissions, and strengthen the competitiveness of the European car industry, is checked. The analysis suggests that issues arise at various levels, and that alternative narratives emerge when considering the behaviour of the system as a whole, including externalization.

1. Introduction

The EU's energy system faces many complex challenges in the near future. Attempts to diminish reliance on imports and to decrease the emission of greenhouse gases (GHG), amid growing levels of energy consumption and heavy reliance on fossil fuels, have proved to be challenging both for policymakers to shape and for governments to implement. The technological lock-in of infrastructure is a further obstacle to be faced in order to move away from the current fossil fueled socio-technological pathway towards a different type of metabolism. With the concept of energy transitions, in particular towards renewable sources of energy, as well as that of low carbon economy gaining momentum across different policy and politics realms, it is important to understand the role that energy plays in the metabolic pattern of society, not simply as an external power source but as a defining element shaping the way society has evolved so far.

From an energetic and environmental standpoint, the transport sector has proven to be particularly problematic. Not only does it consume more fuels than any other EU sector – over 60% in 2015 (Eurostat, 2015) – but it is also a sector which is struggling to make significant changes. In fact, both its consumption and its emissions have been growing over the past ten years (Eurostat, 2015). This is partially due to the fact that transport cannot be externalized: while many industries have moved away from the EU to other countries, giving a false sense of "de-materialization" and emission reduction, transport is inherently local, leaving little room for maneuver when it comes to reducing its impacts. The integration of renewables into the EU's transport sector has also proven to be difficult. The 2009 Renewable Energy Directive set a specific target for 10% of EU countries' transport fuels to come from renewable sources by 2020. The 2016 revised Renewable Energy Directive recognized that transport is "lagging behind the other sectors" and addressed controversies over indirect land use change (ILUC) brought by the implementation of biofuels.

In order to speed up a renewable transition in the transport sector, the Alternative Fuels Infrastructure Directive was implemented in 2014. The directive anticipates the logic of the revised Renewable Energy Directive, which states that lack of appropriate infrastructure is one of the main reasons why member states are failing to meet their renewable transport sector targets. While striving to maintain technological neutrality across different forms of alternative fuels, the Alternative Fuels Infrastructure Directive sets specific targets for those fuels that require a change in infrastructure. Electrification of the transport sector is seen by many as the most likely option for the integration of renewable energy into transport, as the most mature technologies harnessing renewable sources, such as wind turbines and solar panels, are used to generate electricity. In particular, electric vehicles (EVs) have been gaining increasing popularity in political discourses as well as the media. They are often championed as the solution to a wide range of issues, from energy security (Jacobson, 2009) and climate change (Brady and O'Mahony, 2011) to grid intermittency (Kempton and Tomić, 2005) and pollution (Girardi et al., 2015).

The growing importance that EVs are gaining in socio-technological imaginaries is reflected by the number of studies and assessments being produced to answer questions regarding their overall contributions to emissions (Hawkins et al., 2013), their impact on the electricity grid (Hartmann and Özdemir, 2011) and their potential to store intermittent electricity through vehicle-to-grid (VTG) and vehicle-to-home (VTH) mechanisms (Liu et al., 2013). A number of LCAs have been produced to check how EVs compare with internal combustion engines (ICEs), and unsurprisingly the results vary greatly among studies. A recent publication by Tagliaferri et al. (2016) highlights how, when it comes to the energy required for the manufacturing of a battery system, results vary by an order of 300.

LCAs are known to provide varying results depending on the chosen set of assumptions and boundary conditions, however the assessment of EVs proves to be even more challenging due to the fact that the technology is not mature, and that the impacts on the energy system highly depend on the chosen electricity mix and driving patterns (Faria et al., 2013). The assessment of innovations that are still not widely implemented is tricky, and providing exact figures that rely heavily on a chosen set of assumptions, both on the production and on the consumption side, does not lead to a better understanding of the effects of the integration of EVs into the current system. Social-ecological systems are complex, and as such the relations among their parts and their evolution through time cannot be predicted.

In this paper, we propose an alternative methodology, called *Quantitative Story-Telling (QST)*, whose aim is to better understand how the metabolism of the system is operating now and what constraints may be posed on its future – not by predicting what will happen, but by checking the quality of underlying narratives being used to describe the system at hand. QST recognizes the inherent role that different framings and storylines play both in the production of information and use of numbers, and in the policymaking process. Framing is “a way of selecting, organizing, interpreting, and making sense of a complex reality to provide guideposts for knowing, analyzing, persuading and acting. A frame is a perspective from which an amorphous, ill-defined, problematic situation can be made sense of and acted on” (Rein and Schön, 1996 found in Lenschow and Zito, 1998). The formulation of policies relies on framing of issues, sometimes simplifying complex problems to a single framing in order to flatten them to one dimension and to be able to propose a direct solution, often in the form of technology (Lenschow and Zito, 1998).

Different frames are also used by scientists in the production of knowledge. In fact, no representation of reality is possible without a chosen storyline. This holds even more for sustainability problems, where “facts (are) uncertain, values in dispute, stakes high and decisions urgent” (Funtowicz and Ravetz, 1993). In such uncertainty, a new type of science must be produced, aiming not at giving exact solutions – such as “which transport form is more sustainable” – but at better understanding the problems at hand, and which payoffs exist when implementing different types of solutions, something that is only possible by recognizing that payoffs are inevitable, and no win-win solution for all actors can exist.

Within this framework, and focusing back to the chosen case study of electric vehicles, the aim of this paper is: (i) to identify the main narratives surrounding EVs in EU documents, and organize them across hierarchical levels; (ii) to perform a quality check of the narratives, by quantitatively assessing whether narratives at the same level clash with each other, and whether narratives across levels hold true. In practice, this is done by developing an analysis to check the effects of a 100% electric vehicle fleet in EU cities on the metabolic pattern of the transport system. In the next section, the methodology of QST is described. Then, preliminary results are presented, with an initial appraisal of three narratives. Finally, preliminary conclusions are drawn, to be expanded on in the final version of the paper.

2. Methodology

As outlined in the Introduction, Quantitative Story-Telling (QST) is a methodology that recognizes the importance that storylines have in the organization of quantitative information and in the decision-making process. Therefore, in section 2.1 an overview of the tools used for narrative mapping is provided, while in section 2.2 we provide a synthesized version of the tools used for the quantitative assessment.

2.1. Narrative mapping

In order to identify the main narratives attributed to alternative fuels, and specifically to electric vehicles, a text analysis of the 2013 Clean Transport Package, together with documents associated to it, is carried out.

Table 1: Documents analysed

Type of document	Name	Year	Code
Directive	Deployment of alternative fuels infrastructure	2014	2014/94/EU
Communication	Clean power for transport: a European alternative fuels strategy	2013	COM(2013)17
Communication	Proposal for a directive on the deployment of alternative fuels infrastructure	2013	COM(2013)18
Press release	European parliament vote “milestone” in the roll out of clean fuels or transport	2014	IP(14)440
Memo	Clean power for transport – frequently asked questions	2014	MEMO-13-24
Press release	Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions	2011	IP(11)372
White paper	Roadmap to a single European transport area – towards a competitive and resource efficient transport system	2011	COM(2011)144

The aim of the text analysis is to identify different types of narratives operating at different levels, specifically: *what* the EU wants to achieve in terms of sustainable transport, *how* it wants to achieve it and *why*. The aims and means change when going from lower to higher levels: the final aim at a certain level (for example, to decrease emissions), becomes the means to achieve a goal at a higher hierarchical level (for example, to decrease emissions in order to mitigate the climate change). A hierarchical organization of narratives, following the definition of level hierarchy proposed by Lane (2006), helps us identify how different storylines are linked, and at which points quantification can become a useful tool.

The organization of narratives across hierarchical levels will become clearer in the Preliminary results section, where electric vehicle narratives are mapped – the first part of this section will provide a mix of methodology and results, as the best way to describe the proposed methodology is through a practical example.

2.2. Metabolic analysis

In the quantitative part of the analysis, we check the metabolic changes brought by one of the goals highlighted by the 2050 Transport Strategy, i.e. the full integration of electric vehicles in cities, and how this related to the narratives identified in the first step .The analytical part of QST is performed using the method of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). The method has been described in detail elsewhere (see, for example, Giampietro et al., 2014). Here, we highlight the main tools implemented by MuSIASEM for the description of complex systems: the distinction between fund and flow elements, the distinction between structural and functional elements, and the use of processors. For a description of these three concepts, please refer to the methodological summary provided by Parra et al. (2017) in this same issue.

3. Preliminary results

Due to lack of space, a preliminary version of the results is presented, focusing on a limited set of narratives and their quality check.

3.1. Narrative mapping

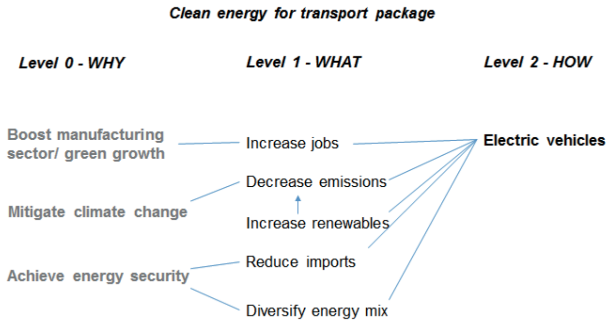

Figure 1: Electric vehicle narrative mapping

The narratives identified in the text analysis are organized across hierarchical levels. A schematic and simplified view of the narratives of the Clean Transport Package is shown in Figure 1 - where the only alternative fuel highlighted is electricity for cars. At the left side of the hierarchical scheme we find the underlying narratives to which all others connect. Following Lane's description of level hierarchy (Lane, 2006), these are the ones with a more extended socio-temporal scale. We can see that EVs are linked to various expected outcomes, and the outcomes can then be mapped onto what we define here as normative narratives, i.e. the accepted values justifying why a certain goal should be achieved. Aside from normative narratives, operating at the level of the whole of society, and setting targets for what *should* be done, the narratives cascading at lower levels reflect *how* these normative goals should be reached. At the interface between level 0 and level 1, quantification is not particularly useful. Here we are still at a generic, ambiguous and politicized level: for example, checking that a diversification of the energy mix improves security is not something to be done with numbers, as it stems from the definition itself of energy security, which moreover is a notably slippery term acquiring different meanings for different actors. The quality check of QTS can be performed at the level 1, and at the interface between level 1 and level 2, looking at:

1. Do electric vehicles (level 2) achieve what they are supposed to achieve (level 1)?
2. Do the level 1 targets contradict each other?
3. Do other alternative tools not appearing in level 2 reach the goals outlined in level 1, and why are they not being favoured?

In the following section, one of the goals of the EU Transport 2050 strategy, i.e. to only have electric cars in cities by 2050, is used to check the quality of three narratives: that electric vehicles will “support economic growth and strengthen the competitiveness of European industry” (European Commission, 2013) , that they will reduce emissions and that they will reduce EU imports.

Table 2: Preliminary quality check of three narratives

NARRATIVE 1		
Core narrative (WHY)	**Specific EV narrative (level 2-->1)**	**Type of narrative**
Boost green growth	Electric vehicles will support economic growth and strengthen the competitiveness of European industry	**HOW-WHAT**: the tool (the HOW) is expected to lead to a desired result (the WHAT)
Issues		
1. The EV production chain requires less labour per car than the ICE one (but more energy)		
2. The EU does not have the industry needed to produce batteries or manufacture EVs		
3. An industry shift would require huge investments and structural changes		
Alternative narrative(s)		
Moving from ICEs from EVs could result in further de-industrialization of the EU and reliance on battery imports		
If industries shift from producing ICEs to EVs, they would more automated, requiring less labour and more energy		
NARRATIVE 2		
Core narrative (WHY)	**Specific EV narrative (level 2-->1)**	**Type of narrative**
Mitigate climate change	Electric vehicles will reduce emissions	**HOW-WHAT**: the tool (the HOW) is expected to lead to a desired result (the WHAT)
Issues		
1. The emissions of electric vehicles depend strongly on the electricity mix		
2. If we include the emissions of material extraction and transport of materials needed to produce batteries,		
EV emissions can be equal or superior to ICE ones (depending on the mix)		
Alternative narrative(s)		
Electric vehicles could lead to a local reduction of emissions, but only because of an externalization of their impact at two levels:		
1. reduction of emissions in cities, being externalized to areas where electricity is produced		
2. reduction of emissions in the EU, being externalized to countries where materials are extracted and batteries manufactured		
NARRATIVE 3		
Core narrative (WHY)	**EV narrative (level 2-->1)**	**Type of narrative**

Achieve energy security	Electric vehicles will reduce EU imports	**HOW-WHAT**: the tool (the HOW) is expected to lead to a desired result (the WHAT)
Issues		
1. Electric vehicles can only cover short term road transport. Urban road transport consumes less than 20% of all oil imported into the EU		
2. Depending on the electricity mix, the EU would have to import primary energy sources to produce more electricity		
3. The EU does not have lithium, or the raw materials needed to produce batteries		
Alternative narrative(s)		
A shift to EVs would not substantially reduce EU oil imports as they can only cover a small section of the transport sector		
Increased electricity needs could lead to an increase in primary energy source imports (such as uranium for nuclear power) as the resulting increase in electricity consumption will require additional power capacity		
If batteries are produced locally, the EU would have to import lithium and raw materials (only available in specific countries)		
If batteries are not produced locally, the EU would have to import batteries (only produced in specific countries)		

3.2. Quality check on narratives

MuSIASEM and relational analysis, with the set of tools described by Parra et al. (2017) in this issue – particularly through the tool of processors – are used for the quantification step of QST, to check the quality of EV narratives across different levels. This is done by disaggregating the different steps in the production chain of EVs and ICEs, as well as the material extraction needed for them, their operation, and the different energy mixes they rely on. A summary of preliminary results relating to three narratives is presented in Table 2. The narratives presented belong the same type, operating at the interface between level 1 and level 2, and their check relies on seeing whether (i) the tool (the HOW) produces the expected result (the WHAT) and (ii) whether it produces other unwanted results (alternative narratives). Other types of narratives, such as clashes between those operating at the same level, will be checked in the final work. It is important to note that the results presented, being still in the preliminary stage, simply point to issues which have appeared through the analysis. Final results will quantify such issues and provide a detailed overview of the situation.

4. Conclusions

In this short paper, we have applied Quantitative Story-Telling to the case study of electric vehicles in the EU. A simplified hierarchical organization of the policy narratives surrounding electric vehicles was presented, followed by preliminary results checking the quality of identified narratives, using MuSIASEM and relational analysis to check the effects of a 100% electric vehicle fleet in cities. Recognizing the role that uncertainty and impredicativity play in the assessment of innovations and how they interact with complex social-ecological systems, the aim was to check whether the narratives adopted by the EU regarding electric vehicles are consistent.

The preliminary results focused on three narratives: that electric vehicles will boost the EU manufacturing sector, that they will reduce emissions and that they will reduce EU's dependence on imports. It was highlighted that the electric vehicle production chain requires less labour and more energy per unit than its ICE counterpart; that the extraction and transport of materials, and manufacturing process, of EVs produces significant emissions, which are lower than ICEs only when certain electricity mixes are considered; and that EVs would only reduce oil imports by 20%, and increase imports either in raw materials and lithium, or in batteries.

In addition to the specific results related to the narratives, the analysis suggests that assumptions on the production side (what electricity mix is produced) and consumption side (how much cars are being used) lead to vastly different results when it comes to the aims of electric vehicles. This means that, when quantifying their sustainability: (i) assumptions should be stated clearly; (ii) a modular and open approach is needed and (iii) absolute results do not exist and cannot be produced. Further work will expand on the preliminary results to include a check among narratives of the same level, and to highlight alternatives available at the level 2 which could produce some of the desired results at level 1, such as car sharing.

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Overcoming the Engagement Barrier in Demand-Side Management Using Social Influence

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Abstract

Achieving long-term household engagement for smart grid demand response is essential in tapping the full potential of the smart grid. This is a difficult task, since the monetary savings from reduced energy use are often too low compared to the lost comfort, appealing to environmental concern is believed to be important, but shows little effect in practice, and initial interest in pure environmental feedback (i.e. from in-home energy monitors) diminishes over time. Recent work suggests that applying social influence together with a sense of community responsibility could increase engagement. Building on a literature review and focus group sessions identifying neighbourhood needs, we propose a *sustainability-oriented social network for neighbourhoods*, aimed at facilitating and enriching local life by helping neighbours connect, as a suitable context for engaging environmental feedback. Providing energy- and demand-response -feedback within the social network, including comparisons with neighbours and highlighting the individual user's contribution to the community, can be expected to increase the environmental awareness of households and their likeliness to participate in demand response programmes compared with conventional feedback mechanisms. This research has the potential to deliver an effective and cost-effective way for energy utilities to engage their customers while increasing the energy awareness of households.

1. Background

Households are associated with 20% of European greenhouse gas (GHG) emissions (Eurostat, 2016), and should therefore be considered an important contributor to the substantial GHG emissions reduction required for keeping the global temperature increase within the internationally agreed limit in the Paris Agreement (United Nations, 2015). This emission reduction requires not only a decrease in energy use, but also a sharp increase of the share of renewables in the power grid (International Energy Agency, 2016). To handle the intermittent power production from renewable energy sources such as wind and solar power, the grid is becoming increasingly 'smart', but the demand-side flexibility also needs to increase (Strbac, 2008). As households are an important contributor to the power demand, smart grids depend on long-term engagement by households in order to reach their full potential (Honebein, Cammarano and Boice, 2011). One common intervention measure requiring engagement is the so called demand response programme (Siano, 2014), which aims to shift and decrease household peak loads.

Achieving long-term household engagement for energy-related measures has proven to be difficult: the monetary savings from reduced energy use are often too low compared to the lost comfort (Hargreaves, Nye and Burgess, 2013); appealing to environmental concern is believed to be important but shows little effect in reality (Cialdini and Schultz, 2004); and initial interest in environmental feedback (i.e. from energy apps or in-home energy monitors) diminishes over time (Hargreaves, Nye and Burgess, 2013). This could be indicative of a technology-push-oriented design approach where feedback solutions have not been designed with the actual needs of households in mind (Pierce et al., 2010).

This study therefore examines how environmental engagement among citizens, especially relating to the use of household electricity, can be increased. Our starting point was recent findings suggesting that displaying energy feedback in a relevant everyday context that is not limited to just environmental sustainability (Pierce et al., 2011; Nyström and Mustaquim, 2014) and using social influence (Fishbein and Ajzen, 2010; Cialdini and Schultz, 2004; Schultz et al., 2007; Allcott, 2011; Knowles et al., 2013) could increase household engagement.

In this paper, we i) identify a context for environmental feedback that has the potential to result in long-term engagement by households, ii) determine a set of design principles for effective environmental feedback, and iii) consider evaluation of the proposed feedback mechanisms in comparison with conventional feedback approaches.

The proposed context, a *sustainability-oriented social network for neighbourhoods*, is based on an extensive literature review and a case study in Hammarby Sjöstad, Stockholm. In particular, the literature about user engagement and local social capital was reviewed. This was combined with focus group discussions aimed at identifying neighbourhood needs in Hammarby Sjöstad. Furthermore, to draw on best practices in designing the energy feedback, relevant literature on individual (in-home displays) and comparative (energy reduction competitions) energy feedback, combined with literature about behavioural psychology and human-computer interaction, was reviewed

2. Design principles for energy feedback

The aim with providing household-level energy feedback is to get a reduction and/or shift in household energy use. As a large part of household energy use can be linked to behaviour (Gram-Hanssen, 2011), a good understanding about behavior-changing mechanisms is important. Therefore, we analyse below how behavioural psychology, comparative feedback, suitable behaviour change strategies and social influence can assist in design of an effective energy feedback in a social setting.

2.1. Psychology and behaviour

Psychology research in the form of the Theory of Planned Behaviour (Ajzen, 1991) and its successor, Reasoned Action Approach (Fishbein and Ajzen, 2010), suggests that human behaviour is affected by three factors: i) attitudes (will the behaviour benefit us?), ii) perceived behavioural control (can we do it?) and iii) social influence: how we think important others want us to behave (injunctive norm) and how we think others actually behave (descriptive norm). Based on these three behaviour-affecting factors, well-designed energy feedback should aim to: i) increase environmental awareness by making the receiver understand that helping to save the environment benefits everyone, including themselves, ii) inform the receiver that they can easily contribute by providing concrete energy-saving tips and examples of load-shifting actions, and iii) include social norms such as comparisons with others. Moreover, as every individual places different weight on each factor and the factors affect each other (Fishbein and Ajzen, 2010), there is probably no “one size fits all” way to increase engagement. Instead, the feedback should be tailored to give maximum effect (Abrahamse and Steg, 2013).

Behaviour can also be regarded as driven by different types of motivation, often divided into intrinsic motivation, meaning that the action in itself is interesting or enjoyable, and extrinsic motivation, where the action is taken in order to achieve some other goal (for example, earning money by carrying out a boring task). For longer-term engagement, the focus should be on affecting intrinsic motivation and integrally regulated extrinsic motivation (Ryan and Deci, 2000). According to Self-Determination Theory (SDT) (ibid.), intrinsic motivation can be awakened by a combination of competence (i.e. feeling that one can perform the action) and autonomy (that one can decide whether to perform the action). Feedback should therefore be actionable, which resonates well with Ajzen's (1991) perceived behavioural control, and should not be perceived as 'forced'.

2.2. Comparative feedback

Household energy consumption is a vital piece of information when showing energy feedback. However, this information in isolation is not enough (Darby, 2006). Using a car analogy as an example, most drivers develop an intuitive feeling for whether their current driving speed is appropriate in the current situation (driving past a school or on an empty motorway), and it can also easily be compared against what 'others' think is proper (the speed limit). This kind of intuitive feeling does not apply to home electricity use, as there is no natural frame of reference: most people cannot tell whether their consumption is 'appropriate'. Adding a frame of reference to the feedback, such as a comparison to similar households or consumption goals, is therefore necessary.

Allowing for comparison with past consumption can be effective (Darby, 2006; Vine and Jones, 2015). Giving end-users this type of comparison (and also comparisons with similar households) is in fact recommended by the European Union in article 13 of Council Directive 2006/32/EC. Furthermore, if the consumption data is high-resolution and real-time, it can provide better insights about actual electricity use in home appliances, and thereby permit more informed decisions that lower negligent energy use. However, even when providing households with historical comparisons and real-time data, feedback based only on the household's own consumption fails to achieve long-term engagement: a few months after the installation of an in-home energy display, the initial excitement has typically been lost and the display becomes 'backgrounded', i.e. "embedded in the 'background' of everyday life" (Hargreaves, Nye and Burgess, 2013). One possible reason for this is that it no longer offers any 'new' information (ibid.). Thus, the feedback could be improved by adding a changing element that keeps the user interested.

2.3. Energy reduction competitions and behaviour change strategies

Energy reduction competitions typically aim to reduce energy use and increase awareness of energy-efficient behaviours. In a review of 20 competitions, Vine and Jones (2015) listed effective behaviour change strategies, including: comparative feedback, rewards, education, gamification, local trusted messengers/neighbours, social networking and loss aversion. They also suggested that local competitions lead to more personal engagement than national or international competitions, and that continuous participant engagement throughout the competition is a key factor and is especially successful if the participants can be convinced that their contribution matters. Further, they pointed out that none of the competitions they reviewed was longitudinal, and identified a risk in the types of motivation they generated. For example, if the motivation to compete is purely extrinsic, e.g. winning a prize or gaining bragging rights by taking top place in a ranking list, it is probable that people will return to their old habits after the competition has ended.

2.4. Social influence

As mentioned in the section on behavioural psychology theories, people are affected by others around them. Cialdini and Schultz (2004) suggest that people are often unaware of how strongly this social influence, in particular descriptive norms (what others do), can affect behaviour. When they surveyed Californian residents about top reasons to save energy, the three most important motivators given were environmental concern, social responsibility and self-interest (saving money), while descriptive and injunctive social norms were believed to be the least important motivators. However, in a follow-up field experiment where Cialdini and Schultz gave energy feedback to households based on the top three motivators, the effect on electricity usage was minimal. In fact, the social motivator that people believed in least proved to be the most effective, as the largest electricity use reduction was obtained using feedback containing a descriptive normative message saying that a certain percentage of the neighbours are conserving energy.

However, utilising only descriptive norms when presenting energy consumption can lead to undesirable 'boomerang' effects, since when already energy-efficient households learn that they have lower consumption than the average (i.e. what 'others' consume; the descriptive norm), they may increase their energy use. Interestingly, adding an injunctive norm to the message seems to prevent this boomerang effect. Even a very simple addition such as adding a smiley face (your behaviour is approved by 'others') has proven to be effective (Schultz et al., 2007). Building on these findings, this type of combined descriptive and injunctive feedback has been successfully used in a customer engagement platform for electricity utilities developed by the company Opower (Allcott, 2011). In a combined randomised controlled trial study of almost 600 000 households, the average energy use reduction for the households that received periodic energy feedback information by mail was 2%. This reduction was achieved through better cost effectiveness (cost per saved kWh) than that of many interventions in conventional energy saving programmes. Moreover, the energy use reduction seemed to be relatively long-term, as it was shown to be sustained for the two years in which the data were collected and feedback was given.

Feedback based on social influence should be carefully designed and utilised, however. In their meta-analysis of the field, Abrahamse and Steg (2013) identified social influence methods in general as being effective to drive behavioural change. However, social comparison, one of these methods, was not in itself proven to be very effective. Furthermore, Knowles (2013) suggests that social comparison leads to a strengthening of so-called Self-Enhancement values that are in direct opposition to the self-transcendence values recommended for sustainable human-computer interaction (HCI) studies.

In summary, humans are social beings and their attitudes and behaviour are significantly affected by social influence. This knowledge should affect the feedback context and feedback design. Social needs also played a role in the choice of context for this study, as can be seen in the next section.

3. Finding an engaging, everyday context

Smartphones have become increasingly popular worldwide over the past decade. The always-available content and instant, worldwide communication made possible by digital technology is enticing and, at its best, empowering and educating, giving people access to information and thus allowing them to make better choices. Tapping into this engagement and empowerment potential by using a digital, communication-centric context would appear to be a good strategy for reaching the goal of increased user engagement.

As mentioned in the background section, the potential for environmental feedback to be noticed and acted upon increases if it is displayed in an everyday, frequently used context.

Generally, when a product or service becomes frequently used, this indicates an underlying *user need*. As the aim is to target households, our design approach rests on identifying *household needs* (market-pull) relevant to the engagement problem of energy utilities (technology-push) (Goncalves Da Silva, Karnouskos and Ilic, 2012). A number of household needs were explored as possible intervention strategies for integrating household energy feedback, including the need to be able to stay updated with real-time information about the surrounding area (traffic, public transport, crime, and relevant news) (Ectors, 2014), a joint family calendar for planning household-related tasks, and a household health and stress monitoring application to monitor household well-being. The need that was most compatible with the intended aim was identified by a strong trend best articulated by William Hayes (2007): “globally connected yet locally isolated”. People have rapidly become globally connected, with numerous social networks providing real-time interactivity with friends and family around the globe, public figures and organisations, and colleagues across continents. At the same time, there has been a trend for increasing ‘local isolation’, exemplified by the fact that more than half of Americans (Smith, 2010) and over 70% of all Swedes living in an apartment (Postkodlotteriet, 2016) only know a few, if any, of their neighbours well. This local isolation erodes the local social capital (Putnam, 1995) – the very fabric that holds societies together. One way of increasing local social capital is related to neighbours. They often have locally relevant information that is not readily available online and has the potential to be helpful in numerous ways. The chosen context should therefore provide a way that helps neighbours connect, in order to reverse this trend of ‘local isolation’.

Having recognised the potential for a digital, neighbour-connecting communication platform containing a social aspect, we decided to explore the idea of using a *social network specifically targeted at neighbourhoods* as a context. In order to discover neighbourhood needs that would be facilitated by such a social network and to design features that catered for those needs, neighbourhood-based focus groups were consulted.

Five focus groups were established (see Table 3.1) among residents from Hammarby Sjöstad, an eco-district in Stockholm. During autumn 2015, on average 2-3 meetings were held with these groups, each consisting of 4-8 members, to define priorities for the residents. One focus group, led by a researcher and aiming to discuss general neighbourhood needs, consisted of local residents recruited during a community event; 15 people signed up, of which five attended the focus group meetings. The other four focus groups explored the local needs within the following theme areas: housing cooperatives; environment; culture and local associations; and school. These groups were established and (in all cases except housing cooperatives) led by local individuals chosen for their strong engagement and their local leading role within their area. At least one researcher was present in all groups except for the school group. The five focus groups, the lead roles and the main discussion findings are presented in Table 3.1.

Table 3.1: Findings from focus group discussions in Hammarby Sjöstad, Stockholm, regarding neighbourhood needs. '-' represents something negative, '+' something positive, '•' an observation, '?' a suggestion and '!' an identified need.

Name, description, lead role	Discussion results
FG1: Residents Five residents from the area Lead: Researcher from KTH	**General neighbourhood needs and opportunities** - There is no comprehensive list of current events - There is poor coverage of local news - Information from the municipal authority and city hall is lacking • Existing interest in organic and locally produced food ! Existing need for facilitating and saving time in everyday life **Local trust and safety** - When construction work is done, information to nearby residents about what is being done and how long it will take is lacking. In addition, the residents usually have no way of giving input prior to or during the work even though it affects their local surroundings. - Using Blocket (Sweden's largest classifieds site) does not always feel safe + The area is generally perceived as safe. • The existing Facebook group is the primary channel to report/discuss incidents and to report lost and found items ! One place for all types of error/incident reporting would be nice
FG2: Housing cooperatives Four board members from local housing cooperatives Lead: Researcher from KTH	**Needs of housing cooperative boards** - Getting an updated list of members is difficult, conflicting information is provided by different actors - An internal discussion forum that can be used for raising sensitive topics such as problems with pests and vermin is needed - Having a dialogue about co-operatively owned spaces is a complex task ! Better coordination is needed among housing cooperatives in tendering processes involving subcontractors. ! A single place for error reporting is needed
FG3: Environment Five board members (no overlap with FG2) from local housing cooperatives, having an interest in energy and the environment. Lead: Energy manager in one of the housing cooperatives	- The residents think they are environmentally friendly enough because they use district heating, they don't realise that many of their daily actions affect the environment - Apart from monetary savings, there is no reason for housing cooperatives to be environmentally friendly; an interest needs to be awoken ? Gamification could be used to reduce [energy] consumption ! Showing energy saving tips to residents would be nice ! A possibility to compare energy consumption between housing cooperatives would help their boards understand whether their own consumption is too high
FG4: Culture & Local Associations Seven representatives from cultural associations in the area Lead: Manager of the local cultural association	**Needs of local cultural associations** ! An event calendar is needed, it is difficult to know what is happening in Hammarby Sjöstad. ! Internal discussion groups could be of use, but the greatest need is to inform others in the area ! Rating and reviews of events could be of interest
FG5: School School IT coordinator and a number of parents. Lead: School IT coordinator	**Needs of local schools** - Digital tools for schools already exist, no need for new tools • Do not want to expose children to advertisements ? Could pupils be involved in creating content such as news or events as part of school assignments? ! Crowdfunding could be used to gather money for school projects, classes etc.

The main needs identified by the focus groups were related to a better way of local communication about various issues of importance and different types of local events. These communication needs were reflected in the design of the proposed social network as described in the next section.

4. LocalLife – a Sustainability-Oriented Local Social Network

Based on the outputs from the focus groups and the literature review, we developed the concept of a sustainability-oriented local social network called LocalLife. It is designed to blend the digital neighbourhood with the physical neighbourhood and functions on three urban scales: the building/housing cooperative, the neighbourhood and surrounding neighbourhoods. It caters to everyday needs in a neighbourhood by strengthening neighbour-to-neighbour interactions, in which building- or neighbourhood-level local interest groups can be created, either ad hoc by neighbours or by existing organisations.

The different urban scales and interest groups allow for separate communications: private internal discussions can be held within housing cooperatives and interest groups, while sending a message to the neighbourhood or surrounding neighbourhoods quickly spreads information to a large area. This design has the potential to meet most of the local information- and communication-based needs identified by the focus groups as shown in Table 4.1. Peer moderation is used as a way to minimise inappropriate content.

Table 4.1. Benefits of a communication platform on different urban scales according to identified needs

Urban scale	Benefits	Fulfilled needs identified by the focus groups (from Table 3.1)
Building/housing cooperative	- Allows for private communication within the cooperative for discussing sensitive matters - Gives the board an easy way to communicate with its members and supplies recent contact details for each member	- FG3: An internal discussion forum for the housing cooperative - FG3: Need for an updated list of members
Neighbourhood / surrounding neighbourhoods	- A channel for communication and for spreading information about local news and events. - A way of citizen empowerment by facilitating discussions about important community matters.	- FG1: Better information about current local events - FG1: Better coverage of local news - FG1: Better and more frequent information from the municipal authority and city hall - FG5: Need for an events calendar - FG6: Need for channel for pupils to create local content
Interest groups	- Creates bonds between neighbours - Allows local organisations to spread information to the neighbourhood.	- FG5: Channel for local groups/organisations to inform others in the area about events etc.

4.1 LocalLife as a Context for Energy Feedback

Being a social network, LocalLife is by its nature a social context, and it is expected to be frequently used since it caters for neighbourhood needs identified by the authors and in focus group consultations. This means LocalLife should be suitable for energy feedback, according to the literature. By showing feedback as part of this frequently used context, it should have greater chances of being noticed by the residents compared with conventional feedback contexts such as web pages provided by energy utilities, energy apps or in-home energy displays.

Household energy consumption can be compared with that of similar households (descriptive social norm), while also enabling collective comparison and feedback on the housing cooperation and neighbourhood level. This collective feedback is expected to decrease the boomerang effect of already energy-efficient households by making them part of a collective reduction effort. The dynamics of the neighbourhood, with new neighbours joining, others moving away, and some hopefully changing their behaviour, by itself adds a changing element to the feedback. Gamification elements could make it even more appealing, especially to younger residents. The feedback, including any energy-saving tips, can be individually tailored, possibly based on different types of personas. According to the literature, feedback based on these design principles has the potential to be effective.

The visual appearance of the energy feedback has not yet been determined, but the initial plan is to show it as an expandable energy widget (that can be clicked to show an overlay of detailed information). One advantage of having full control over LocalLife is that the feedback design, its placement and its intertwining with other features of the social network can be fully controlled and customised, which would not be possible had the feedback been included as part of an existing social network such as Facebook. For example, this allows the energy widget to utilise space that would commonly be occupied by advertisements and enables deeper links to the content of the social network, such as showing encouraging and/or spurring posts about the household's or the neighbours' energy performance in relation to individually set goals, creating periodic energy reports, having energy savings competitions, and including gamification that could give rewards such as badges or some form of virtual currency usable for other future services within the network.

The electricity consumption data for the energy feedback, provided in hourly or monthly resolution, will be collected from the local Swedish distribution system operators (DSOs). In order for LocalLife to gain access to household consumption data, each household needs to give its consent. This process normally requires the user to find their meter id, sign a printed contract and send it to the DSO, a task that probably only the most environmentally interested users would complete. In order to increase the chances of getting a larger user base for energy feedback, we have been cooperating with one of the largest DSOs in Sweden, resulting in an easier and fully digital consent process that can be initiated from within LocalLife.

4.2 LocalLife as an Enabler of Social Sustainability

LocalLife is designed not only to provide a context for energy feedback and thus increase environmental sustainability, but also to help increase social sustainability when introduced in an area. Local needs are met through offering possibilities for communication and self-organisation of neighbours, thus facilitating everyday tasks such as getting a recommendation on a local dentist, notifying neighbours about a lost wallet, borrowing a tool, initiating a local project and quickly alerting neighbours about local incidents. The increased frequency of communication and physical meetings between neighbours is expected, in turn, to increase aspects of social capital such as the feeling of place identity, social cohesion, safety and trust. The latter is also an important enabler for the sharing economy; as local social capital and a sense of trust increases, eventually neighbours may feel more comfortable participating in sharing economy activities that require a higher degree of trust such as car-sharing or babysitting. As sharing economy activities are usually less resource-intensive than conventional options, in both an economic and environmental sense, it can be concluded that an increase in local social capital also has the potential to increase both environmental and economic sustainability in a neighbourhood.

5. Discussion and Conclusions

Finding ways to engage households in contributing to the demand-side flexibility required in future smart grids is a complicated task. This study started by summarising design principles for energy feedback found in the literature. Next, taking into account the importance of a social context and social influence, recognising the increasing 'local isolation' in today's neighbourhoods and building on a need for local communication expressed by focus groups, we developed LocalLife – a sustainability-based local social network for neighbourhoods – as a suitable context for providing engaging energy feedback to households. This mixing of energy feedback in a social network is a novel approach for overcoming the residential engagement barrier in the smart grid.

Energy feedback utilising social influence has the potential to lead to long-term behavioural change. This has been shown by the company Opower: the deployment of its user engagement platform has not only led to a successful large-scale, sustained energy use reduction among households (Allcott, 2011), but the company has also introduced the 'low-tech' concept of 'behavioural demand response'. Without any reliance on home-side automation, but by simply prompting users to reduce their energy use during peak hours and by providing neighbourhood comparisons, an average peak load reduction of 2.6% over 200 000 North American households was achieved, according to a case study in summer 2015 (Opower, 2015). In contrast to Opower's low-tech social approach, a more 'high-tech' pilot project including, but not particularly emphasizing, conventionally designed energy feedback is being carried out during 2017 in Stockholm Royal Seaport, another eco-district, as part of the Active House subproject in the Smart Energy City research programme[1]. Each of the around 150 apartments has a home automation system that can be controlled from a wall display or a mobile app, both of which also display real-time energy feedback. The Active House pilot focuses on demand-response, where residents are expected to shift their loads away from the daily peaks based on a price signal, either manually or by scheduling their washing machines and dryers.

However, Opower and the Active House approaches are both still inherently technology-push-oriented. It would therefore be valuable to explore how the 'mid-tech', needs-based approach used in LocalLife compares against these. We plan to carry out such a comparison as part of the LocalLife pilot in Stockholm, with the aim of measuring whether our approach can achieve even higher engagement, resulting in larger energy savings and a higher average peak load reduction. Another area to explore is whether introducing a local social network into a neighbourhood leads to an increase in social sustainability aspects such as trust, safety and local identity. Closing the loop, these social aspects are sometimes positively correlated to local environmental awareness (Uzzell, Pol

[1] smartenergycity.se

and Badenes, 2002). If that correlation were better understood, it could inform the design of future local demand response programmes and local environmental campaigns.

Looking at some of the limitations of this study, one apparent replicability limitation is the selection of the neighbourhood, given that the district Hammarby Sjöstad is a particularly affluent neighbourhood of Sweden with a strong environmental profile. Furthermore, it was designed as a so-called ‘eco-district’ and initially intended for sustainable lifestyles. Thus its demographics and subcultures may not be representative of many other areas in Swedish and European cities. However, LocalLife will also be deployed in other, more representative areas in Sweden, such as Årsta in Stockholm, Västra Hamnen in Västerås and Storsudret on Gotland.

It is important to note that most HCI-oriented sustainability studies, including the present study, are inherently interdisciplinary (Silberman et al., 2014), requiring expertise from power systems, informatics, computer science, human computer interaction and economics and behavioural sciences. Moreover, the application of a socio-technical system approach (Geels, 2004) to smart grids involves a transdisciplinary research design, meaning co-creation among researchers and non-academic stakeholders such as DSOs, housing cooperatives, municipal actors and households. While transdisciplinary research is a difficult endeavour, we argue that challenge-driven social networks targeting sustainability goals can scarcely be researched and designed otherwise.

In conclusion, this paper proposes a novel design approach to overcome the user engagement barrier in smart grids. It rests on identifying an appropriate and real end-user need, developing a solution to meet that need and integrating demand response feedback in the resulting context. A local social network, aimed at facilitating and enriching everyday life in the neighbourhood, was designed to function as a context for individual and collective energy feedback on neighbourhood level and for feedback from demand response programmes. Future pilot studies will assess its efficacy in terms of social and environmental sustainability.

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Evaluation of energy metabolism in the oil extraction in Ecuador from the application of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM)

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Abstract

The global structure of primary energy is supported mainly by the production of hydrocarbons. In 2016 more than 85% of primary energy was from hydrocarbons (oil, coal and natural gas). Oil and natural gas together accounted for about 60% of world production (IEA, 2016). The use of oil and natural gas as a source of energy for society, demand large amounts of energy and consumption of other resources such as water, soil, human activity, etc. This varies to a greater or lesser extent by: nature of resources, intensity of extraction and versatility in the technological application of industrial processes.

The objective of the study is to propose an alternative tool to develop energy accounting in the oil extraction sector based on the MuSIASEM methodology and to identify the metabolic patterns present in the production units at the different levels and scales of the system.

Ecuador's oil extraction sector was taken as a case study, although its size is marginal at world level; the internal processes of the system are similar in other countries that produce oil. Therefore, to have metabolic factors per unit of production, allows to identify modular reference points that can easily be scaled to the analysis in other geographic spaces.

By collecting and organizing bottom-up data in the form of processors, it is shown that oil extraction in Ecuador consumes in 2016 about 110 kWh of electricity, 1.3 GJ of fuel and 2.1 hours of Human activity per cubic meter of production. The analysis also determines additional flows and funds that will be seen in the development of the work and that serve to understand the dynamics of the system based on its metabolism.

1. Explanation of methodology

1.1 Functional and structural elements of oil extraction

The analysis of the oil extraction system was done using the theory of funds and flows developed by Georgescu-Roegen in 1970 and applied in MuSIASEM by Giampietro in his various works. To summarize, funds are elements whose identity remains intact over the chosen spatial and temporal scale of analysis, while flows are elements that either enter the system without existing, or exit it without entering. Funds need to be maintained in order to be able to metabolize flows (Giampietro,2014).

The funds and flows are always metabolized in a processor that is characterized by its functionality or its structure. Structural processors describe a process taking place through a specific technology or method. The characteristics of this processor reflect the technical coefficients determined by the organizational structure of the specific process. Functional processors, on the other hand, describe a process whose aim is to provide a function within a wider system. The characteristics of this processor are defined by the expectations of the system (the context), that is by the function that has to be expressed to stabilize the metabolism of the larger whole. In complex systems organized over different hierarchical levels this distinction is case dependent as it can change according to the level, scale and goal of the analysis. Then, for each function different structures expressing it can be identified, depending on the goal of the analysis. In the current study, we will only analyze oil extraction as a functional processor in the integrated oil system. By operating at a lower level of analysis in the extraction, we split the functional processor of oil extraction into two further sub-functions: extraction of medium oil and extraction of heavy oil, based on the API gravity described in the following table.

Table 1: Classification of oil by API gravity

API gravity(°)	Classification
>31°	Light oil
22° - 31°	Medium oil
10° - 22°	Heavy oil
<10°	Extra heavy oil

It was not considered light oil because it represents less than 1% and extra-heavy oil because there is no production.

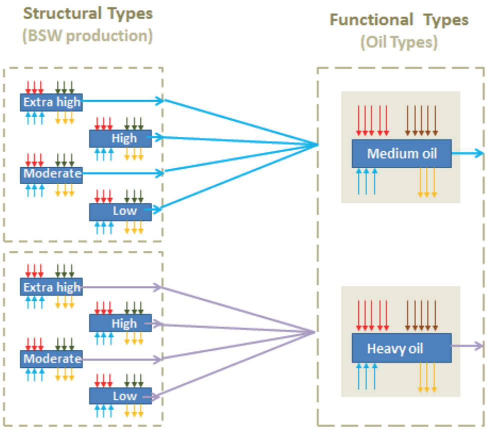
For each sub-function we identify different structures of oil extraction, depending on the amount of Base Sediment Water (BSW) present in the process of extraction. The categorization based on BSW is clarified in Table 2. The four structural types vary depending on the type of oil extracted, and not all types have each structural element – for medium oil in Ecuador, for example, only high BSW and moderate BSW extraction methods are carried out. The structural distinction based on amount of BSW is chosen for this case study, as the funds and flows associated with oil extraction are highly dependent on the amount of total fluid (referring to both crude oil, water and gas) extracted, and not only on the total amount of crude oil extracted.

Table 2: Structural categorization based on BSW production

BSW	Structural type
>90%	Extra high
60% - 90%	High
30% - 60%	Moderate
<30%	Low

Processors are built for each structural element, mapping the input and output flows and funds. In the figure we zoom in into the current case study to show our chosen functional and structural processors.

Figure 1: Structural and functional processors of the case study



2. Results and discussion

2.1 Building a bottom up grammar

In order to build a bottom-up energy grammar, the first step is to characterize the structural and functional elements of the system. Processors are built for each structural element, mapping the input and output flows and funds. In Table 3, extraction blocks in Ecuador are classified based on the type of oil extracted.

Table 3: Ecuador's extraction blocks classified based on functional oil product

#	Block		Production (km3)	%	°API	Type of oil
1	2	GUSTAVO GALINDO	67	0	36	light
2	1	PACOA	2	0	33	light
3	49	BERMEJO	142	0	31	medium
4	64	PALANDA YUCA SUR	124	0	24	medium
5	53	SINGUE	266	1	27	medium
6	60	SACHA	4221	13	26	medium
7	44	PUCUNA	115	0	31	medium
8	56	LAGO AGRIO	224	1	29	medium
9	57	SHUSHUFINDI	6790	21	27	medium
10	58	CUYABENO-TIPISHCA	1534	5	26	medium
11	46	MDC SIPEC	471	1	24	medium
12	47	PBHI	289	1	26	medium
13	52	OCANO-PEÑA BLANCA	138	0	23	heavy
14	12	EDEN YUTURI	2293	7	23	heavy
15	18	PALO AZUL	659	2	23	heavy
16	61	AUCA	3942	12	22	heavy

17	7	COCA PAYAMINO	1874	6	22	heavy
18	10	VILLANO	621	2	19	heavy
19	62	TARAPOA	2016	6	21	heavy
20	45	PUMA	38	0	16	heavy
21	65	PINDO	230	1	20	heavy
22	54	ENO - RON	241	1	13	heavy
23	15	INDILLANA	1683	5	20	heavy
24	21	YURALPA	330	1	17	heavy
25	31	BLOQUE 31	973	3	18	heavy
26	43	ITT	487	2	14	heavy
27	55	ARMADILLO	13	0	13	heavy
28	59	VINITA	36	0	15	heavy
29	66	TIGUINO	138	0	20	heavy
30	14	NANTU	211	1	19	heavy
31	17	HORMIGUERO	338	1	19	heavy
32	16	IRO	1245	4	15	heavy
33	67	TIVACUNO	211	1	19	heavy
		Total	**31960**			

Table 4 shows examples of processors for an structural element: heavy oil production with high BSW. The same data is collected for all eight structural processors of the figure 1 . Data characterizing the inputs and outputs of the processor, as explained previously, are categorizes based on the fund-flow model, and based on whether they are internal (coming from and going to the “technosphere”) or external (coming from and going to the “biosphere”).

Table 4: Examples of flows and funds for three structural processors.

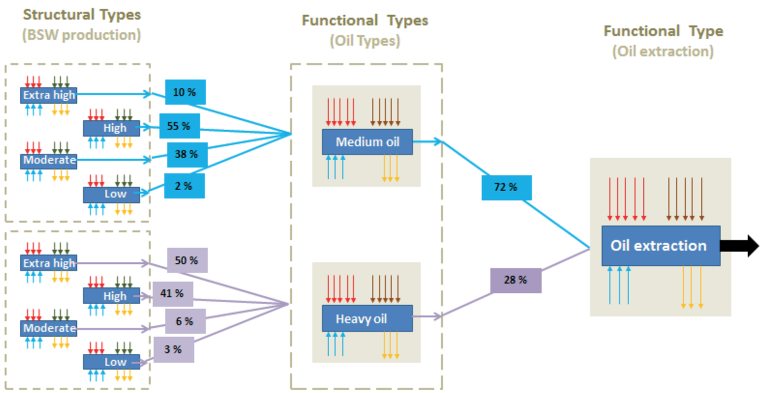
Heavy oil production / high BSW						
Internal Flows	Electricity auto-consumption	**kWh**	358785629	**kWh/m^3**	100	ARCONEL
Internal Flows	Fuel for generation	**GJ**	4733479	**GJ/m^3**	1.3	ARCONEL
Internal Flows	Diesel	**GJ**	1652736	**GJ/m^3**	0.5	ARCONEL
Internal Flows	Natural gas	**GJ**	2206094	**GJ/m^3**	0.6	ARCONEL
Internal Flows	Oil	**GJ**	874649	**GJ/m^3**	0.2	ARCONEL
Internal Flows	Fuel for combustion	**GJ**	967515	**GJ/m^3**	0.3	ARCH / Parra
Internal Flows	Diesel	**GJ**	942210	**GJ/m^3**	0.3	ARCH / Parra
Internal Flows	Gasoline	**GJ**	25304	**GJ/m^3**	negl.	ARCH / Parra
Internal Founds	Power Capacity	**kW**	150019	**kW/m^3**	43	ARCONEL /PAM
Internal Founds	Human activity	**hours**	15247448	**hours/m^3**	4	MICSE
External Inflows	Fluid	**m^3**	23440806	**m^3/m^3**	7	ARCH
External Inflows	Raw water	**m^3**	569752	**m^3/m^3**	0.2	ARCH

External Outflows	Water for reinjection	m^3	19860977	m^3/m^3	6	ARCH
External Outflows	Gas to burn	m^3	53025635	m^3/m^3	15	ARCH
External Outflows	CO2	kg	306809266	kg/m^3	86	Parra
Output	Heavy oil	m^3	**3579828**	m^3	**3579828**	ARCH

2.2 Scaling to the overall extraction processor (functional)

The three functional processors can now be scaled up forming an overall processor characterizing oil extraction in Ecuador, as shown in Figure 2, where a further step is added on the right hand side. Table 5 collects the processors for each functional type (medium and heavy oil), their relative weight and the final intensive and extensive processor for oil extraction. As for the step in the previous sub-section, this is achieved by simply considering the percentages of different functional types of oil with respect to total oil extracted. The intensive characterization of the processor (technical coefficients describing the profile of inputs requirement per unit of output) can then be converted into an extensive one (a description of the profile of inputs and outputs in quantitative terms) by multiplying its intensive inputs and outputs by the scaling factor, in this case the total amount of oil extracted. Intensive processors are useful as they provide qualitative information (technical coefficients) that can be scaled up or down and used as benchmarks for other countries and case studies, while extensive processors provide an overview of the quantities of flows in the specific case at hand.

Figure 2: Scaling functional processors to the final oil extraction one



This quantitatively simple step is methodologically essential: by up-scaling processors from bottom-up structural data, to functional groups, to a final extraction processor, we can simultaneously assess the overall inputs and outputs of the oil extraction sector, and how the individual parts forming this sector contribute to the metabolism. By typologising oil extraction into functional groups, the relative contribution of each type of extraction can be easily checked.

From the data shown in Table 5, we can see that over 70% of oil currently extracted in Ecuador is of medium weight. When it comes to flows and funds consumed by the different types of oils, heavy oil is the most intensive both in terms of electricity and fuel consumption.

Table 5: Building the final oil extraction processor. Numbers may not add up due to rounding

Processor Elements	Label	Unit	Medium oil	Heavy oil	% Medium oil	% Heavy oil	Intensive processor		Extensive processor	
							Unit	**Value**	**Unit**	**Value**
Internal Flow	Electricity auto-consumption	**kWh/m^3**	71	207	72	28	**kWh/m^3**	108	**kWh**	3460046334
Internal Flows	Fuel for generation	**GJ/ m^3**	0.8	3	72	28	**GJ/ m^3**	1.3	**GJ**	41490482
Internal Flows	Fuel oil	**GJ/ m^3**	negl.	negl.	72	28	**GJ/ m^3**	negl.	**GJ**	193461
Internal Flows	Diesel	**GJ/ m^3**	0.3	0.8	72	28	**GJ/ m^3**	.0.4	**GJ**	13501833
Internal Flows	Natural gas	**GJ/ m^3**	0.2	0.7	72	28	**GJ/ m^3**	0.3	**GJ**	10772120
Internal Flows	Oil	**GJ/ m^3**	0.3	1	72	28	**GJ/ m^3**	0.5	**GJ**	17023068
Internal Flows	Fuel for combustion	**GJ/ m^3**	0.2	0.3	72	28	**GJ/ m^3**	0.2	**GJ**	7239488
Internal Flows	Diesel	**GJ/ m^3**	0.2	0.2	72	28	**GJ/ m^3**	0.2	**GJ**	6195163
Internal Flows	Gasoline	**GJ/ m^3**	negl.	negl.	72	28	**GJ/ m^3**	negl.	**GJ**	270924
Internal Flows	Natural gas	**GJ/ m^3**	negl.	negl.	72	28	**GJ/ m^3**	egl.	**GJ**	773401
Internal Founds	Power Capacity	**kW/ m^3**	21.3	60	72	28	**kW/ m^3**	32	**kW**	1022157
Internal Founds	Human activity	**hours/ m^3**	1.6	3.4	72	28	**hours/ m^3**	2	**hours**	67470065
External Inflows	Fluid	**m^3/ m^3**	4	14	72	28	**m^3/ m^3**	7	**m^3**	216408201
External Inflows	Raw water	**m^3/ m^3**	0.2	0.2	72	28	**m^3/ m^3**	0.2	**m^3**	7199532
External Outflows	Water for reinjection	**m^3/ m^3**	3	13	72	28	**m^3/ m^3**	6	**m^3**	184497642
External Outflows	Gas to burn	**m^3/ m^3**	36	13	72	28	**m^3/ m^3**	30	**m^3**	957030364
External Outflows	CO2 (electricity generation)	**kg/ m^3**	54	161	72	28	**kg/ m^3**	84	**kg**	2666028197
Output	Oil production	**m^3**	23044086	8797248			**m^3**	31910559		

Considering water use, we saw in Figure 2 that 65% medium oil uses high or extra high BSW, while over 90% of heavy oil is extracted with high or extra-high BSW. This is reflected in the amount of water needed for reinjection, which is considerably higher for heavy oil compared to medium. It's important to note that this is because of the structural processors used now to extract heavy oil, and not necessarily because heavy oil produces more BSW *per se*. This multiscale analysis makes it possible to predict the effect of different combinations of lower level typologies of processors when considering scenarios – and this may avoid to reach wrong conclusions based on reasonable guesses. This will be clear in the following sub-section.

Looking at Ecuador's 2016 metabolic pattern for oil extraction, we can see that:

- On average, over 100 kWh of electricity are needed for each cubic meter of crude oil extracted;
- Approximately 1.5 GJ of fuels are consumed for each cubic meter of crude oil extracted: most of them (1.3 GJ) are used to generate electricity on site, and the rest to operate machinery;
- As for funds, approximately 3 kW of power capacity are needed per unit of oil extracted, and 2 hours of human activity, including both direct (operational) and indirect (administrative) jobs;
- Considering water use, almost 8 cubic meters of fluid (water, gas and oil) are extracted for each cubic meter of oil recovered – 0.2 cubic meters of freshwater are consumed per unit of extraction, and almost 6 cubic meters of water are reinjected;
- Finally, the oil extraction sector contributes to overall CO2 emissions by producing almost 84 kg of CO2 per cubic meter of oil extracted.

This framework is useful for two purposes. Firstly, it allows us to have a detailed description of the flows and the funds consumed by Ecuador's oil extraction sector, as briefly outlined, identifying the relevant elements of the system. Secondly, the characterization of these elements in the form of processors allow checking how the combination of various elements of the oil extraction process contributes to its final metabolism, and how changing the relative weight of the elements affects the flows and funds of the final oil extraction processor.

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Back to the Future

Gilberto Gallopín[1]

Abstract

The world system is at an uncertain branch point from which a wide range of possible, qualitatively different, futures could unfold in this Century. Two decades ago, the Global Scenario Group published three archetypical sets of scenarios of the future of the planet. These are revisited in the light of the changes and developments that happened since then, as well as the emerging new trends, looking for meaningful early warning signals and potential strategic causal nodes that could help steering towards a sustainable global future.

1. Introduction

In many of the discussions and proposals regarding future developments and the quest for sustainability, in the energy field as well as in many others, an unstated and critical assumption is that the future will be a more or less gradual unfolding from the present, without large discontinuities and surprises.

It is clear that, despite progress in some fronts, current trends are proving to be ecologically (UNEP 2012, MEA 2005)) and socially (UNDP 2016) unsustainable, suggesting the likelihood of ruptures in the historical trajectory. A number of global critical trends affecting the future were identified and discussed in Gallopín et al. (1997), under the headings: economic growth, population growth, technological change, decentralization of the economy, equity, resource depletion, pollution and global environmental change. The only certainty is that the future will not be projection from the past, and that uncertainty will be paramount.

We are living amidst a confluence of many rapid, and some unprecedented, megatrends. The fundamental uncertainty about our future as a species and as elements of the global socio-ecological systems (or "Earth System") to which we belong, comes from the deeper impact of the fusion and interactions among those social, technological, economic, cultural, and environmental processes, and not just by the simple summation of those. And these megatrends operate within a strongly connected (and increasingly so) system, the Earth System. A large number of causal links are known, but many more have not yet been identified. Thus, we are facing large uncertainties associated with these megatrends within a global system whose structure and dynamics we only partially know. This situation is a critical one: new opportunities may open (but can we identify and act timely to bring them into being?), but large threats also loom ahead (Gallopín, 2016)

One way to gain insights into an uncertain future is to construct scenarios. This technique has been used since the 1970's to bring issues of environment and development to the attention of both scientists and policymakers. The scenarios summarized here are those developed about 20 years ago by an international and interdisciplinary group of 15 development professionals called the Global Scenario Group (Gallopín et al., 1997; Raskin et al. 1998, 2002).

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A scenario is essentially a story about the future. It indicates what the future may be like, as well as how events might unfold. Unlike projections and forecasts, which tend to be more quantitative and more limited in their assumptions, scenarios are logical narratives dealing with possibly far-reaching changes (Kahn and Wiener 1967, Schwartz 1991, Cole 1981, Miles 1981, Godet 1987). A scenario includes possible course of events leading to a resulting state or image of the future world. Scenarios are most emphatically not predictions, but ways of exploring the possible futures.

2. The scenarios of the GSG

Three basic scenarios were produced by the Global Scenario Group (GSG) with two variants each. These were (see Figure 1 for an impressionistic depiction of the final images of the world in each scenario):

1. Conventional Worlds, deriving without sharp deviations from present, having the variants Market Forces and Policy Reform.
2. Barbarization, incorporating the possibility of deterioration in civilization, as problems overwhelm the coping capacity of both markets and policies, with the variants Fortress World and Breakdown.
3. Great Transitions, contemplating visionary solutions to the sustainability challenge, including fundamental changes in the prevailing values as well as novel socio-economic arrangements, with the variants Eco-communalism and New Sustainability Paradigm.

Figure 1. The family of images of the future under the GSG scenarios

All of them unfolded from the same set of driving forces or trends that were expected to critically influence the global future.

Space limitations preclude presenting in detail the cause-and-effect unfolding of the scenarios; those can be found in Gallopín et al. (1997), Gallopín and Raskin (1998), Raskin et al (1998, 2002).

2.1 Conventional Worlds

The Conventional Worlds scenarios include a continuation of generally extant processes and forces. Markets and private investment remain the engines of economic growth and wealth allocation. The globalization of product and labor markets continues apace, while transnational corporations dominate an increasingly borderless economy. Consumerism and possessive individualism prevail.

The variant Market Forces is 'business-as-usual' because it assumes that current trends and policies (or lack thereof) are maintained and that development follows a mid-range course (as assumed in many analyses). The variant Policy Reform maintains the essential assumptions of the Conventional World paradigm. But in contrast to the Market Forces, Policy Reform assumes the emergence of a public consensus and strong political will for taking action to ensure a successful transition to a sustainable future. This scenario follows the recommendations of the Brundtland Commission (WCED 1987).

In the Market Forces variant, global population and economy grow rapidly, both in the rich and poor regions, but poverty on a large scale persists and the continued inequality between and within nations generates tensions. Market Forces results in increased environmental and socio-economic stress and a serious loss of resilience, resulting in a global crisis interlacing environmental, social and economic factors. A vicious, self-reinforcing, circle involving economic instability, inefficiency, social and military conflict, and ecological stress becomes established.

In the Policy Reform variant, population grows slower than in the Market Forces. Greater equity is sought between and within regions. Strong policies towards reduction of hunger are implemented. Though the gap between rich and poor nations is far from closed, the level of international equity is twice that of the Market Forces scenario.

The challenge of simultaneously meeting all sustainability criteria is formidable, facing multiple constraints. The tension between the continuity of dominant values and institutions and the goals of greater equity, a reduction in poverty, and protection of the climate and environment will not be easily reconciled and may become critical.

2.2 Barbarization Scenarios

This is a class of scenarios envisioning the possibility that the social, economic, and moral underpinnings of civilization deteriorate, as emerging problems overwhelm the coping capacity of both markets and policy reforms. The resulting tensions due to increasing inequity, massive migrations, and hostility between the have and the have-not could lead to generalized societal disorder, loss of governance, and regional fragmentation.

In the Fortress World variant, the powerful countries ally among themselves to protect their privileged situation by entrenching themselves into "bubbles of wealth" excluding the majority of the world population from accessing resources considered strategic, and controlling the per capita consumption and demographic growth of the disfranchised population. This scenario seems to contain the seeds of its own destruction, but it could last for decades.

In the Breakdown scenario variant, the powerful elites are unable to contain the tide of violence arising from extreme inequity, or unable or unwilling to organize themselves in a gated world. In this case, the outcome of the Barbarization process would be a world characterized by generalized Breakdown, a general disintegration of social, cultural, and political institutions, deindustrialization, and technological regression. Breakdown could persist for decades before social evolution to higher levels of civilization again becomes possible.

2.3 Great Transitions

A variant of the Great Transitions scenario is *Eco-communalism*, based on a deep-green vision of bio-regionalism, localism, face-to-face democracy, small technology, and economic autarky; a patchwork of semi-isolated and self-reliant communities with low economic growth and small population. A trajectory leading from the current world situation directly to an Eco-communalism future is very unlikely. Too much is committed, and Eco-communalism would imply a voluntary dismantling of much of what has been built by civilization, as well as strong reductions in population. However, it could very well arise as a recovery following the generalized collapse associated with the end of the Barbarization scenarios.

The New Sustainability Paradigm could emerge out of a new understanding of the sustainability challenge (and solutions) or as a reaction to some catastrophic event or visible threat. It evolves from basically the current situation through a drastic institutional reorganization and a revival of basic human values.

This variant includes a strong decrease of the pressure upon resources and the environment (through lifestyle changes, stabilization of population growth and dematerialization of the economy), and a decided reduction in social sources of tension and instability such as inequality, poverty, and power imposition, and the flourishing of the forces of solidarity, collaboration, and social creativity. The institutional organization maintains connectedness, but flexibilized through decentralization and establishment of diversified self-organizing units at different scales. The resulting ultra-complex global socio-ecological system could never be managed in a centralized form; a new style of governance based on decentralized, co-operating networks at different scales arises.

3. The new situation

Many things have happened since the original GSG scenarios were published. Some of the changes fit roughly within the trends that were originally identified as the main drivers (presented before) of the scenarios (e.g. acceleration of the technological revolution), but other are novel (global terrorism, sharp trends towards increasing inequality –within and between countries) or acquired new intensities (acceleration of climate change, strong reduction of global poverty).

The relevance of the changes can be exemplified by trends in two different fronts: one social, the other environmental. While poverty has been reduced, inequality has been dramatically increasing, as illustrated in Figure 2. In the climate arena, changes are happening faster than anticipated; furthermore, recent findings from a cross-comparison of the predictions of the main climate models (Drijfhout et al., 2015) show that abrupt changes in the global climate system are exhibited by all models, and eighteen out of a total of 37 forced abrupt shifts occur at global temperature increases below 2° C. This is very alarming, as the target of 2° C or less is the current international political consensus.

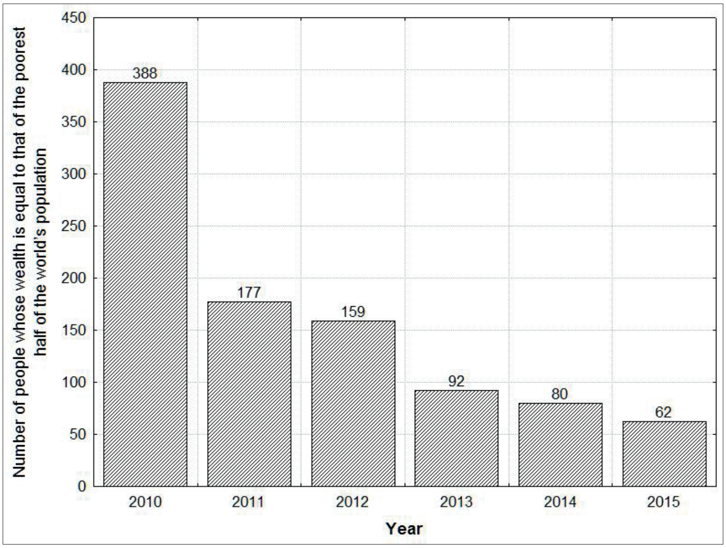

Figure 2. The recent evolution of inequality. Source: Oxfam International. 2016. 62 people own the same as half the world, reveals Oxfam Davos report. https://oxf.am/2t889qt

Some of the most important developments unfolding since the GSG scenarios were presented two decades ago can best gain perspective if grouped under the six main clusters of driving forces as were originally described, in terms of their most relevant elements for driving the trajectories of the scenarios. These original trends are summarized below (in italics). Significant changes during the last two decades are in normal font.

1. *Economic and geopolitical forces: included the end of the Cold War, a universal expansion of the capitalistic system, and an acceleration of globalization*

   1.1. The unipolar world that emerged after the end of the Cold War is changing into a bipolar world with the ascent of China, and probably to a multipolar (oligopolar) world later. Today, the US, China and Japan are the three bigger economies (in that order) and by 2050 it is anticipated the ranking will be China, the US, and India (obviously, within the Conventional World assumption)

   1.2. Wildcard: the election of Donald Trump as president of the U.S. (withdrawal from the global Climate Change agreement, protectionist economic policies, unpredictability)

2. *Social: particularly poverty and national and international inequity*

   2.1. Significant reduction of global poverty

2.2. Unprecedented increase of inequality within and between countries

3. *Demographic forces: included population growth that is concentrated in poor countries and regions, and changing age structures related to youth dominated populations in poor areas and an aging structure in the rich areas.*

   3.1. Increasing number of refugees from armed conflicts.

   3.2. Xenophobia signals in Europe and other parts of the affluent world

4. *Environmental: referred to increasing environmental stress, widespread ecosystem disturbance, and an increase in global ecological interdependence.*

   4.1. Climate Change is manifesting earlier than predicted; the window of opportunity to avoid its worst effects in closing very quickly, if not already closed

   4.2. A number of environmental “planetary boundaries” have already been surpassed (Steffen at al. 2015)

   4.3. Discovery of new shale large oil and gas resources

5. *Technological: assumed the continuation of the technological revolution, the expansion of global information and communications, and the private control of technological innovation and diffusion and of its benefits.*

   5.1. High growth of energy production from renewables

   5.2. Ascent of the electrical car

   5.3. Fast growth in energy efficiency (appliances, lightning, buildings, vehicles)

6. *Global governance: included the continued proliferation of non-governmental organizations, the strengthening of a civil society, and reinvigoration of the United Nations system.*

   6.1. International agreement on the UN Sustainable Development Goals established in 2015 (UN 2016)

   6.2. Emergence and spread of international terrorism

This listing of changes in the driving forces that occurred in the last twenty years is not exhaustive; only those aspects that, in the author’s judgement, seem more significant in terms of moving the trajectories towards to, or away from, the identified scenarios were included. The interactions between the new trends have not been analyzed here; they could intensify or mitigate the impacts. Ideally, the scenarios should be completely redrawn, as new staring points may lead to cause-and-effect unfoldings that follow different trajectories than those originally defined. Here, a simpler analysis is presented, identified the impacts of the contemporary changes in the driving forces as early warnings suggesting which scenarios seem to become more or less likely or, better, which changes are more (or less) compatible with which scenarios.

Table I shows the results of this exercise. The scenarios appear in the columns; first the classes, and to the right, the individual scenarios (because sometimes it may be clear that a new development will be compatible with a class of scenarios, but difficult to determine which individual scenario would be involved). The new trends are presented in the rows.

A + sign indicated that a trend favors, or is most compatible, with the corresponding scenario, or scenario class. A question mark aside a + sign indicates that the influence is unclear and depends on the specific form that the driver adopts and the scenario dynamics.

CONVENTIONAL WORLDS	GREAT TRANSITIONS		Breakdown	Forthess world	market forces	policy reform	eco-communalism	new sustainability
+	+		+	+	+	+		+ ?
+ ?				+		+ ?		
+	+				+	+		+
			+	+				
				+				
				+				
+ ?			+	+		+ ?		
+			+	+		+		
+			+	+	+			
+	+					+	+	+
+					+ ?	+		
+	+					+	+	+
+	+ ?					+		+ ?
+ ?			+	+		+ ?		

Table I. Indicates the impact of the new trends (rows) into the likelihood of materialization of the scenarios (columns). More explanations in the text.

The interpretation of the results in Table I follows.

1.1 Move to oligopolar world. This may affect all scenario classes, depending on the form it takes. If the few great powers feel threatened by the actions (or the mere existence and use of resources) of the dispossessed, a push to the Barbarization scenarios is likely (to the Fortress World if group consensus is reached, Breakdown if internal dissidences and hostilities within the Group of Powers prevail). However, a globally cooperative set of powerful nations could facilitate the move to a Policy

Reform scenario. Or even (but less likely) to a Great Transition one. Even less likely, is the maintenance of the Market Forces.

1.2 The wildcard President Trump might influence the likelihood of different scenarios. The withdrawal of the US from the Paris Climate Agreement may be lethal to an already insufficient set of measures to mitigate climate change. This, together with the impact of the other measures (protectionism, military confrontation with North Korea, policy unpredictability) would lean the future towards the Barbarization scenarios, particularly the Fortress World. On the other hand, if his influence is short enough and the rest of the world make unprecedented efforts propelled by the realization of the approaching abyss, the Policy Reform scenario may become more likely.

2.1 Reduction in global poverty. This trend would be compatible with the Conventional Words scenario Policy Reform or, less likely, the Market Forces scenario. A continued reduction in poverty, if accompanied by cultural and consumption patterns changes, may also accompany a transition to the New Sustainability scenario.

2.2 Increasing inequality. This development will act in the opposite direction of poverty reduction, increasing conflicts and resentment, fueling hostile actions and global terrorism. It most evident effects will be the favoring the Breakdown scenarios, in both Fortress World and Breakdown, depending on the virulence of the reactions and the regulatory capacity of the states.

3.1 Increase of refugees. This would act in the same directions as the last trend, but also increasing the possibility of xenophobic reactions, increasing the likelihood of the Barbarization scenarios (particularly of the Fortress World).

3.2 Increasing xenophobia. This is a clear early warning sign of a transition to a Fortress Word (already partially germinating in the closing of frontiers to refugees by countries of Europe and Middle East)

4.1 Acceleration of climate change. It may be a forerunner of a move towards either of the two Barbarization scenarios (depending on its speed and magnitude, the materialization of abrupt changes, and the reaction capacity of societies). Less likely, it might also lead to a Policy Reform scenario, if and only if the international and national political systems exhibit the will and the capacity to perform actions strong enough, and intelligent enough, to change course)

4.2 Surpassing planetary boundaries. This trend, although less dramatic (or perhaps less understood) would increase the likelihood of the move to the Barbarization scenarios, and maybe to the Policy Reform one, already sensitized by the other negative trends. As human pressures within the Earth System (the interconnected global socio-ecological system) increase, several critical thresholds are approaching or have been exceeded, beyond which abrupt and non-linear changes to the life-support functions of the planet could occur (UNEP 2012)

4.3 New shale resources discovered. This trend, associated with the rapid development of technologies to exploit them, may mask the urgency to move to renewable sources of energy. This in turn may have the consequence of approaching either of the Barbarization scenarios, and also help to the continuation of the Market Forces scenario.

5.1 Growth in proportion of energy from renewables. This trend will be most compatible with the Policy Reform scenario but also with a move towards both Great Transition scenarios.

5.2 Ascent of the electric cars. This movement would be most compatible with a Policy Reform scenario, and (possibly) could help the Market forces world to last longer. Although it could seem surprising at a first glance, electric cars are not an essential component of the Great Transition scenarios, which rely more on public transportation rather than on the use of cars.

5.3 Growth in energy efficiency. It would be an essential element of the Policy Reform scenario, but particularly of both Great Transition scenarios.

6.1 Establishment of the Sustainable Development Goals. If the global commitment is translated into strong actions, it would favor the emergence of the Policy Reform scenario (actually, it would be already an embryonic form of it). It could also be compatible with the New Sustainability scenario. The problem is that the goals have been defined without scrutinizing the many causal interactions among them. Therefore, it is quite obvious that if all goals were simultaneously met, without qualitative changes in the patterns of production and consumption, most if not all planetary boundaries will explode. This critique has already been made (see, for an example, Hickel 2015).

6.2 Emergence of international terrorism. This phenomenon, if it continues to expand (as it will under some scenarios) will contribute to the likelihood of both Barbarization scenarios, and possibly to a Policy Reform scenario (only in the case that the world unites against a common threat and succeeds in minimizing it by addressing its root causes.

4. Conclusions

Seeds of all scenarios can be detected today in the world, but some appear to be growing and expanding, in some places and even globally. It should not be forgotten that scenarios are not predictions, and we cannot (or should not) even try to assign probabilities to them. In the last twenty years, some trends have persisted, and new trends have materialized. Some of the new trends are positive in the sense that could help the materialization of some “nice” scenarios, but others are rather ominous.

None of the trends by themselves (the originally defined trends modified by the new developments of the last twenty years) will determine a change in course, but the accumulations of trends may have a significant impact on the direction the future goes.

The question explored here is: considering the collective of new trends identified, can we say something about which scenarios we seem to be approaching (or moving away from) or even are beginning to materialize, in the perspective of the original GSG scenarios? Because the future does not “come” but it is built by the social actors within the physical and thermodynamic constraints of the world, the accumulation of trend in one or two directions can operate as early warning signals the emphasize the need to steering the changes towards desirable futures.

The impression obtained from an examination of Table I is that the new trends collectively favor, or are most compatible with, the barbarization scenarios, (mainly

Fortress World, but also Breakdown). Initial phases of the Fortress World can be felt in some countries of the European Union and other parts of the world.

To a smaller degree, the set of new drivers could be increase the likelihood of the Policy Reform scenario, although for some drivers this depends on big "if" (effect conditional to an effective and timely reaction of the policy makers, conditions that are not evident today).

In the third place, the New Sustainability scenario appears to be facilitated by a number of trends, some of the also with large "if" questions.

Some trends could be assumed to favor the continuation of the Market Forces scenario, but this, although prevailing today, is the most unlikely scenario by the end of the Century, as It is inherently unsustainable

Strong, effective, timely (the window for changing course is very rapidly closing, as exemplified by climate change) and coordinated actions are urgently required to change the current trajectory. Unfortunately, no positive systemic change is in view; only some ameliorative policies, that do not address qualitative changes in societal values and consumption patterns.

As a faint note of hope, it should be considered that some of the new trends such as the actions of President Trump (1.2), the arrival of climate change (4.1) and the upset of xenophobia (3.2) could also be indicators of the period of disorder and increasing entropy that normally precedes the transition towards a new regime. This is not only a warning signal, but a time during which small actions could self-amplify and strongly co-determine the future path.

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Land requirements for Mediterranean diet: standard agriculture vs new agroecology

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The transition towards sustainable human interaction with the surrounding ecosystem requires a change in the fundamental aspects of its behaviour. Food production is at the cornerstone of our survival and consequently it has the highest priority in the face of declining resources, increasing pollution and population.

Understanding the parameters to judge and quantify methods of food production alternative to the present mono-cultural, energy intensive and mechanized agricultural system is crucial to support, develop and improve new techniques and practices to transition to. Land surface use is one of the important parameters to derive for any given food system. The surface required for food production has strong impact on the care for the ecosystem (avoid soil erosion, impose energy and water efficient usage, set up balance with other living vegetable and animal species, close cycles, set up urban food schemes) and it is correlated with resource usage and feasibility of alternative approaches to deliver nutrition to communities.

The first goal of this study is to determine the typical land surface required in central and southern-Europe to produce the basic elements of the typical Mediterranean diet defined by the Italian Food Pyramid (www.piramideItaliana.it) in a few scenarios combining different diets, techniques and regions. The scenarios will range from food production for an omnivore diet to a vegetarian diet, both including or excluding typical cereal-based food and obtained by using both standard mechanized agriculture and examples of alternative agroecological techniques in specific regions (bio-intense, synergic, organic..). The second goal is to compare land surfaces obtained in the different scenarios.

The analysis method is to use the yields per surface and per year available in the FAOSTAT public database for food products and derive a robust estimate for surface yield for each product by averaging over space (production in central and southern Europe countries) and time (over about 10 years of production data). Similar yields for alternative agroecological will be obtained by literature, small scale experimental setups and local organizations (particularly obtained from the center of Italy). Such yields derived for different techniques and regions will be combined with the different dietary requirements to provide the land surfaces to be compared.

The scenario comparisons allows to determine a first immediate, easily visualizable sustainability parameter to correlate with food production organization in communities and with the associated resource basis (fuel, fertilizer, water..).

Food-Energy-Water Nexus Analysis in Urban Circular Economy Strategy

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Abstract

Growth of urban population around the world and, particularly, within urban areas, has placed various pressing challenges on food, energy, and water (FEW). FEW resources consumption by increasing urban population caused various environmental impacts, such as organic waste generation from food consumption, municipal wastewater and air emissions from urban energy consumption. The current study on urban energy-water-carbon coupling is mainly focused on the correlation analysis of elements by pairs, while these works are developed separately. With respect to the methods, the existing research mostly adopts the bottom-up approach, accounting for the direct relationship between the individual production sectors, given a certain technical level for a chosen process. The economic sector division within the system is rather rough. Thus, the limited outputs make policy recommendations less effective. Moreover, the existing research is presently in the stage of accounting for energy, water consumption and carbon emissions, while the association between the internal elements of the system still lacks of simulation. This study describes a pre-prototypal version of an online open access tool for cities, the Urban Circular Economy Calculator (UCEC), which will transform the existing data into useful information for managing FEW nexus though the development of different circular economy scenarios. In particular, UCEC v1.0 uses Beijing data as test case. In particular, 10 water-related policies, 8 food-related policies and 10 energy-related policies were selected. FEW pathways and policy scenarios can be user-defined for other cities and supplemented into the calculator (for the future versions). Long-term simulations are provided by the calculator to test the trajectories of Circular Economy policy effects under different environmental, economic and social assumptions. Furthermore, processes optimization and debugging will take place. Different strategies can be selected to address long-term challenges to the megacity's economy. Being an open access tool, UCEC can be used also for supporting participatory processes as an urban management instrument. UCEC is a low-cost, technologically feasible, easy-to-use online Circular Economy Solutions Platform. It is based on available up-to-date accounting tools and on simple technical requirements. The only critical point (data availability for other urban contexts) can be overcome using the open access option, which enables a mutual cooperation among developers and end-users. Thus, the UCEC community will be able to share the necessary data, based on the previous definition of intellectual property and, eventually, privacy requirements for critical inputs. Nonetheless, no private critical data will be required, since they are not necessary for UCEC. The necessity of such a tool is proved by the societal need of transition toward a low-carbon and sustainable framework, which can be effectively supported by the introduction of circular economy. This transition, such as the idea behind UCEC, should preserve (or even improve) the societal wellbeing, while increasing basic resources (i.e.: FEW) accessibility, security and preservation.

1. Introduction

Growth of urban population around the world and, particularly, within urban areas, has placed various pressing challenges on food, energy, and water. First, growing urban population increases the already existing stress on the sustainable supply of FEW resources to urban dwellers. For example, cities are now responsible for 7% of the global freshwater withdrawal, account for over 70% of global energy use [1], and consume over 50% of the global food supply [2, 3]. As global urban population is expected to grow 1.8% annually in decades to come [3], the provision of FEW resources faces numerous challenges such as production, resilience, safety, and security.

On the other hand, FEW resources consumption by increasing urban population caused various environmental impacts, such as organic waste generation from food consumption, municipal wastewater and air emissions from urban energy consumption. For example, air pollution resulting from urban energy consumption threatens public health in many countries [4-9]. Fossil fuel consumption by cities contributes to 40-50% of global GHG emissions [2]. Whereas fossil-fuel combustion is primarily responsible for the increase in CO2 emissions, agricultural activities are primarily responsible to disruptions in the nitrogen cycle, which has been disrupted to an even greater extent than the carbon cycle [10]. Anthropogenic disruptions in the nitrogen cycle led to a 1,100% increase in the flux of nonreactive atmospheric nitrogen (N2) to reactive nitrogen compounds [11]. The National Academy of Engineering identified managing the nitrogen cycle as one of the fourteen Grand Challenges for Engineering in the 21st Century [12].

The current study on urban energy-water-carbon coupling is mainly focused on the correlation analysis of elements by pairs, while these works are developed separately. With respect to the methods, the existing research mostly adopts the bottom-up approach, accounting for the direct relationship between the individual production sectors, given a certain technical level for a chosen process. The economic sector division within the system is rather rough. Thus, the limited outputs make policy recommendations less effective. While efficiency improvements represent an unprecedented opportunity to address the urban FEW challenges, we must consider the urban FEW systems simultaneously when developing policy and technology solutions, since FEW systems are interconnected in complex ways and interdependent with each other.

The project aims at developing an online open access tool for cities, the Urban Circular Economy Calculator (UCEC), which enables to develop different circular economy scenarios associated to Food-Energy-Water (FEW) management. UCEC v1.0 uses Beijing data as test case. In particular, 10 water-related policies, 8 food-related policies and 10 energy-related policies were selected. FEW pathways and policy scenarios can be user-defined for other cities and supplemented into the calculator (for the future versions). Long-term simulations are provided by the calculator to test the trajectories of Circular Economy policy effects under different environmental, economic and social assumptions. Furthermore, processes optimization and debugging will take place. Different strategies can be selected to address long-term challenges to the megacity's economy. Being an open access tool, UCEC can be used also for supporting participatory processes as an urban management instrument.

2. Materials and methods

We developed a prototypal Urban Circular Economy Calculator (UCEC) based on the integrated systems modelling framework, which allows to draw and analyse different urban circular economy scenarios with respect to Food-Energy-Water (FEW) nexus. This solution, based on a full urban dynamic model, enables the visualization of calculation of different circular economy pathways, foreseen saving of resources and related costs of different planning options for FEW nexus, given both the existing specific urban statistics and foreseen urban scenarios as input by local administrators. The calculator, which explores policy and technology solutions for improving the efficiency of the urban FEW systems, was developed using Beijing (China) [13, 14] as case study. More than twenty scenarios were chosen for testing the Calculator, such as: (a) 10 water-related policies; (b) 8 food-related policies; (c) 10 energy-related policies. In order to establish such a FEW Calculator, we developed a static flow and stock network for each of the FEW systems within the spatial boundary. Alternative policies can be selected using the calculator, as visible from the screenshot reported in Figure 2. In addition to existing FEW interdependences shown in Figure 3, many new linkages can be created for waste recycling and reuse (e.g.: organic wastes can be used to generate electricity, heat, and biogas to supplement the urban energy supply; nutrients in food wastes as well as wastewater can be recovered for reuse using different methods and technologies). Therefore, the transition from a linear to circular economy pattern can be foreseen.

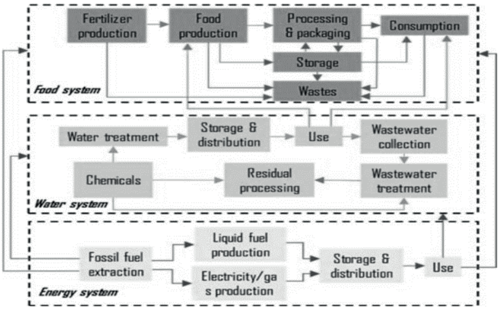

Fig. 1 Conceptual framework of urban FEW system. Processes can be physically located outside the urban area

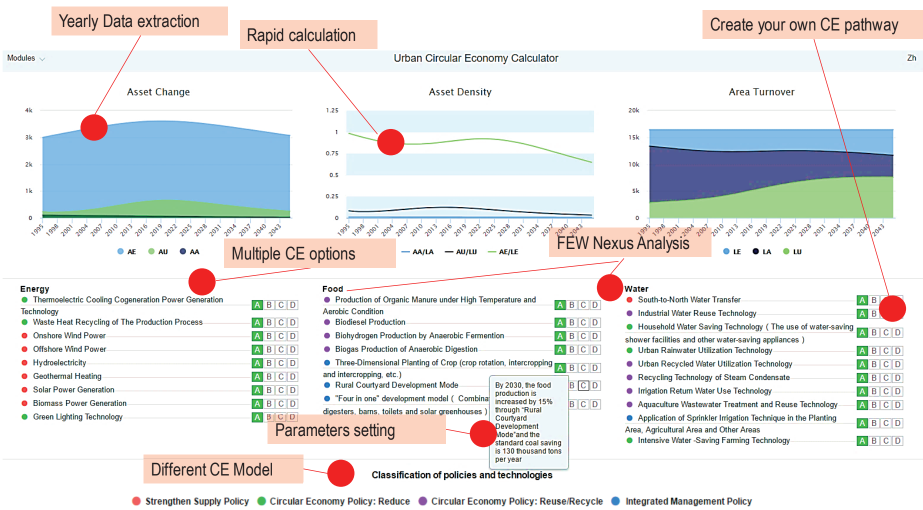

Fig.2 Alternative FEW policies and visualization

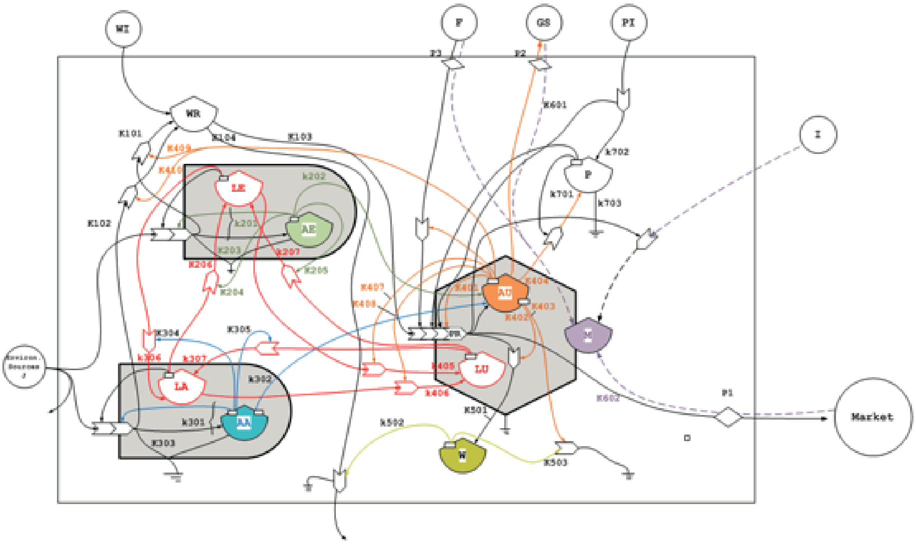

Fig.3 Example of urban energy flow network in Beijing

How does this calculator fit into practice? UCEC will provide a picture of the transition during the interim years by simulating the scenarios of different circular economy policy options. UCEC will support the choice among alternative food-energy-water (FEW) tactics permitting the forecast of developing trend of a system. The urban structure is understood as the compound of three subsystems: food, energy and water. Food system includes food production, processing, storage, consumption, and the management of organic wastes. Production and processing phases consume water and energy. Fertilizer production and use release nutrients, mainly nitrogen and phosphorus, to water bodies, that may contribute to urban water supply. Organic wastes from food processing, storage, and consumption also discharge nutrients to municipal wastewater streams. Water system primarily comprises water treatment, storage and distribution, wastewater collection, wastewater treatment, and residuals processing. Water is used in the food system for food production, processing, and consumption, and in the energy system as cooling water for electricity production. Water and wastewater treatments both consume energy. Energy system structure is finally reproduced.

The basic underlying concept is urban metabolism, which assesses the relationship between resources and waste behind the use of resources. This study 'visits' the internal urban metabolic mechanism and flow process, providing the research foundation for explaining and exploring the key processes within FEW nexus. Planning development, while taking into consideration the impact on FEW nexus, poses the question of responsibility. When a greater number of stakeholders and sectors become involved in the decision-making process, policy-makers and developers need to pay special attention to risk and responsibilities, and ensure that both are shared equitably. Thus, the outputs of this research are able to provide new insights for the solution of urban ecological environmental problems. Moreover, this project will advance the science and engineering of FEW nexus modelling, identifying the positive synergies in

FEW nexus for urban areas. The emergy-based Urban Circular Economy Calculator bridges the gap between detailed Food-Energy-Water Pathway and regional economic indicators, and illustrates the flow and collection of energy and material intuitively.

Modelling the integrated urban FEW systems needs to address the following challenges: (1) Spatial distribution of urban FEW supply chains. Although we focus on FEW resources for urban areas, their supply chains span across regions and nations. We need to define an appropriate system boundary for modelling urban FEW systems; (2) Temporal dynamics of urban FEW systems. FEW resources can be produced, processed, and consumed in either short term (e.g., electricity production, wastewater treatment) or long term with stocks (e.g., food products, water storage), showing strong temporal dynamics. We need to capture such temporal dynamics in the modelling; (3) Complexity of the network of FEW networks. Individual FEW flows can be characterized as networks. Their interdependence makes a network of networks. We need to be able to analyze this network of networks with meaningful metrics to characterize its structural features; (4) The general application to megacities in different countries. For this type of modeling, a huge amount of regional information is required to formulate a model that mimics real-world mechanisms in a satisfying manner of different areas.

We will address the first challenge by using urban water system as a benchmark for system boundary. In contrast to globalized product commodities flows, such as food and energy, urban water flows are spatially-bound by proximate ecosystems, providing a clearly defined system boundary to locate and quantify stock-flow origins and dynamics [15]. The second challenge will be addressed using dynamic material and energy flow analysis (DMEFA). MEFA is based on mass (energy) balance principles: mass (energy) input to a system is equal to the sum of mass (energy) output and net change of stocks. DMEFA describes the material or energy flows of a system over a time interval [16, 17]. The third challenge will be addressed through Ecological Network Analysis (ENA), which will be used to examine relationships between ecosystem compartments [18]. Complex Network Analysis (CNA) will be used to examine the topological patterns of interconnectedness in complex systems [20]. ENA evaluates the impacts of material or energy inputs on downstream outputs of ecosystem compartments (supply-push [19]). On the other side, CNA offers metrics and techniques to measure the relative importance of nodes to the entire network and the structure of the entire network (e.g., clustering, hierarchy). We will select appropriate metrics and methods from these fields to examine the structure of the integrated urban FEW networks. For addressing the last challenge, we will modify the parameters of the model. It is also required to assess the functional form of the relations.

3. Results and discussion

UCEC v1.0 uses Beijing data as test case. In particular, 10 water-related policies, 8 food-related policies and 10 energy-related policies were selected. FEW pathways and policy scenarios can be user-defined for other cities and supplemented into the calculator (for the future versions). Long-term simulations are provided by the calculator to test the trajectories of Circular Economy policy effects under different environmental, economic and social assumptions. Furthermore, processes optimization and debugging will take place. Different strategies can be selected to address long-term challenges to the megacity's economy. Being an open access tool, UCEC can be used also for supporting participatory processes as an urban management instrument.

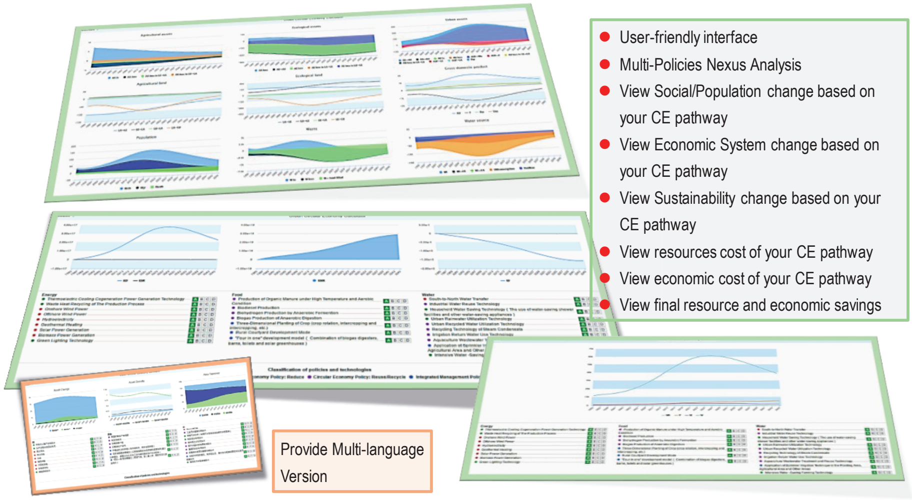

Fig.4 Scenario analysis based on UCEC

UCEC represents a unique future opportunity though the scenario options, which were changed from trajectory A to D in our test case. The presupposed scenarios will provide different pathways for the desired Circular Economy future. In the case of Beijing, the first tests of UCEC v1.0 showed that: (W) available water resource will satisfy the agricultural and urban production activities and the cross-boundary investment (e.g.: water transfer) will be quickly increased, which brings the increase of whole cost. But the financial assets will eventually decrease due to considerable consumption caused by the expansion of the city can't be met; (E) A slow recession in a low-power state of Beijing can be retained. Generally speaking, Beijing can maintain a good balance the external environment in case of energy-saving measures application; (F) Compared with various recycling methods, all composting facilities show relatively low economic efficiency, while the whole cost will be sharply increased. Anyway, UCEC will provide the interface for other circular economic policies in any other countries as well, modifying the parameters input accordingly.

Importantly, UCEC also examine the interactions among the circular economy related technologies to explore the potential for co-benefits and/or trade-offs of addressing multiple costs at the same time, which can provide critical information for policy and investment decisions. For instance, if an energy option is changed from trajectory A to D in our test case (with a consequent change of operating cost), the whole cost of the pathway will be slightly increased.

UCEC will mobilize a big number of international expert institutions, based on their expertise related to global circular economy practices. in particular, we refer to institutions that house global models, data and analyses on global urban futures. UCEC will draw upon state-of-the-art assessments undertaken by the various Circular Economy Solutions Network Thematic Groups (e.g., Deep Decarbonization Pathway

Project, Sustainable Cities, etc.), and data from across the urban networks as inputs to the platform. UCEC, thanks to the support of different partners, will combine models, datasets, and economic analyses, with updated assessments of future circular economy developments and costs/benefits (e.g., WEF technologies selection) and a better understanding of consequences of altering the processes of planetary boundaries beyond a safe operating space. Consequently, we will be able to generate the 1st generation of global urban scenarios, that meet the twin objectives of Circulation Economy Development and Zero Emissions. This will provide improved evidence to political leaders and other key decision makers, on the feasibility, challenges and opportunities associated with meeting long-term development goals. UCEC will provide the open access option to guarantee the preservation of an up-to-date instrument, where stakeholders participate, together with developers, to the individuation and overcoming of technical limitations, while increasing constantly the database of solutions, which can be shared worldwide. This might give a further benefit, since it would allow policy-makers to envisage different solutions developed in different contexts. Thus, local managers might be able also to develop adaptive solutions taken from different urban areas with similar needs.

4. Conclusion

This paper describes an online open access tool for drawing future policy scenarios with respect to FEW nexus. The pre-prototypal version, focused on Beijing as case study, will be further developed, to include a dashboard, where the present available data will be converted into useful and usable information for policy-makers. UCEC will enable both policy-makers to have a ready-to-use instrument for active planning of circular economy roadmaps, as well to improve the possibility of bottom-up participatory processes, supporting the visualization of different circular economy alternatives, focused on FEW nexus, and, consequently, participatory decision-making actions.

Acknowledgements

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Local mechanisms to support energy system balancing aligned to the current electricity grid state

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Abstract

This work conceptualises the alignment of pre-specified semi-automated demand-side management options to the current power grid state to anticipate the distributed provisioning of grid-stabilising services and adaptable loads steered by grid-sensitive tariffs. Paralleling this strategy with congestion pricing from traffic systems, the possible roles of technology and incentives are investigated given the dynamics of involved processes. Staying within boundaries of physical system requirements through our logic could contribute to transformative change if it were embedded in a future energy system that values cooperative coordination across actors towards shared responsibilities for electric infrastructures and grid stability. The role of ICT and frequent information exchanges for control in smart grid environments is challenging and insecure[1]. Instead, infrastructures should be designed to incorporate flexibility options from diverse sources and to allow systems to "fail gracefully" (Bollinger, 2014).

While the stochastic components of electric loads can be averaged, and assumed less relevant if aggregated, system changes induced by more electric vehicles (EV) could be significant due to the correlative component of their charging. If those aspects remained technologically, regulatory, behaviourally and financially uncoordinated and if mechanisms for regulation do not adhere to sensitive rules of local problem solving, as Tesla already employs, severe challenges could be faced. Infrastructures on sub-regional aggregate level might be burdened with problems alike the 50.2Hz rule. Hence, we propose a contractual coordination tool based on grid-sensitive tariffs in accordance with decentralisation and localisation, i.e. solving problems where they occur instead of communicating to a central controlling agency. This is in line with the decentral coordination approach, following biomimicry from ecosystems onto energy sub-systems in the form of cells, as has been proposed by the VDE[2], Germany. Our approach aims to contribute to the resilience of energy systems through increased flexibility on small spatial scales, such as in the residential sector. We propose coordination strategies based on other drivers than time-of-use- or critical-peak-pricing, as load adaptations happen in response to the current grid state (voltage, frequency). We explore distributed remuneration rules of grid-friendly mechanisms, the transferability of dynamic tolling strategies from the traffic sector, and incentives in providing options across the flexibility mix, thereby enabling grid balancing (Acatech, 2015).

We work with assumptions on human flexibilisation potentials and on classifications for technological equipment from the eco-grid EU task force on smart appliances study, given data on the environment (local grid state). The human side is mapped through a Device Relevancy Ranking (DRR), marking socially negotiable practices that affect electricity demand. We identify novel rules and stress the importance of different grid-friendly mechanisms and their fitting into system structures and actor roles. In this, we add a piece to the puzzle for coordination frameworks of future grid structures and contribute to building another control system through incentives and through an improved specification of households' needs linked to consumers' preferences. Based on this, novel contracts can be made possible and the technical connection conditions appropriately set. The increased availability of storage, EVs, and second life batteries from EVs as well as their possible roles in the grid, vehicle to grid (V2G), will further adapt not only the temporal dynamics but also the burden to the grid. These roles can include storage as well as grid balancing services. Therefore, it is practically helpful to provide analyses that can assist in designing mechanisms for the provision of such services. We provide insights firstly through a conceptual approach, where relative temporal dynamics are aligned from the grid and the household consumption side, which we then statistically with data from a rural household.

Keywords: decentralised balancing mechanisms, grid-sensitive operation and tariffs, energy system resilience, grid stability, micro-flexibilisation options.

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1 http://www.zeit.de/2014/16/blackout-energiehacker-stadtwerk-ettlingen - smart grid as "an escalating dependence on multiple, interwoven layers of vulnerable technology" http://energy-reality.org/wp-content/uploads/2013/10/32_Cap-the-Grid_R1_072113.pdf

2 https://shop.vde.com/en/vde-study-the-cellular-approach

1. Introduction

This work brings together options of automatic decentral and distributed load control with the parallel of dynamic tolling mechanisms as are customary in traffic systems. The envisioned scenario would operate based on the premise that minimal communication is needed and information about the current state of the grid is retrieved at each relevant location through measuring the voltage and frequency. Shifting the focus onto grid-friendly mechanisms (GFM), which operate on very small time scales and would be sensitive to time delays, necessitates this assumption.

Steering mechanisms for transiting societies from fossil-fuel to renewable-energy based can be tricky to coordinate across different sectors and responsibility areas. While in the European energy landscape, developments in energy markets and bottom-up initiatives have a longer history, a discrepancy exists in the developing world to provide energy access, amend energy poverty and to determine regulatory, socio-technical and financing options for leapfrogging unsustainable development pathways. We propose a simple strategy that can be applied in both contexts, though possibly more immediately useful in off-grid or island contexts. We describe possible services that could be provided by prosumers under a common pool resource logic, where in a thought experiment the boundaries, roles and rules are blurred. To describe such concepts and options, we use the term co-prosumption.

While other studies are focusing on the details of maximising (local) renewably-generated electricity, our approach is starting out from the options for pricing the automatically regulated GFM scenario. While the tariff structure can be flat, nonlinear, or coupled with performance and contributions to grid stabilisation, the important difference to our approach is the localised contractually pre-determined component and the driver or trigger being the current grid requirements based on its ‘health’. The research question on the micro-level is on how to employ and price GFMs, while on a meta-level we are concerned with an appropriate fit of decentral flexibilisation options and a responsible use and management of the grid infrastructure. This approach contributes to alleviating peak demand and to balancing the demand and supply to amend grid congestion by employing strategies from traffic congestion solutions.

The presumption that smart metering can lower the environmental impact of energy systems depends on how this calculation is framed and on the choice of measurement units. Energy consumption in most developed countries at the household (HH) level, with few exceptions, is usually measured in absolute terms in kWh and priced accordingly. If aggregated as such, this leaves little insights about the temporal aspects of energy consumption or relative effects onto local grid stability. Temporally aggregated energy savings that might be achieved through whichever measures, might still require large capacities to be upheld and maintained. It is the total peak demand values (measured in kW) as well as sudden large amounts of electricity such as demanded by EV (fast / unregulated) charging, which occur possibly correlated and in several temporal sub-sections of the year that impact on the grid, supply constraints, grid extension and capacities. The estimation of peak values and their simultaneity are a main factor used to dimension the power lines and cables.

Our bottom-up perspective describes technological and human adaptability and conjectures how to operationalise these for micro-level flexibilisation. This can help firstly to balance the grid in any time instant (not limited to peaks) and secondly to keep capacities within bounds, and thus to install appropriately dimensioned infrastructure systems. Adding sufficiency options into this equation bears the potential to radically adjust provisional needs, which is in line with our commons-based perspective.

1. Review

Sonnenschein (2015a) proposed flexible scheduling and decentralised load management for batteries and EV charging for demand side management (DSM) through dynamic self-organised clustering. Their approach is market-oriented and aims to maximise the use of local electric feed-in of solar-PV. Kani (2014) investigated real time dynamic Demand Response (DR) with a load frequency control (LFC) model. Asmus (2010) juxtaposes virtual power plants (VPP), microgrids, and the utility-dominated smart grid. He finds that microgrids could well be able to supply ancillary services. Both, Asmus (2010) and Colson (2010) investigated the challenges and opportunities of microgrids islanding. Furthermore, Colson (2010) proposed methods for multi-objective, multi-constraint optimisation frameworks, as well as computationally intelligent methods for seeking Pareto optimal solutions in real- time microgrid power management. Wijaya (2015) employed a Cluster-based Aggregate Forecasting (CBAF) strategy for domestic energy consumption.

For an engineering study of prosumer scenarios and the interplay between prices (per kWh) and incentives of solar-PV plus storage systems across three countries (Texas, Ontario, Germany), Kazhamiaka (2017) investigated jurisdictions' impact on the profitability, given grid pricing, feed-in tariffs and other incentive schemes. Their analysis differentiated between low, medium and high consumption HHs. With profitability measured by the return on investment (ROI), flat prices were compared to different time-of-use (ToU) price strategies. They considered the radiation profile, typical residential loads, cost of system components, price of grid electricity, and incentive programmes on PV and storage system adoption and illustrated how across the three jurisdictions, the adoption of such systems can be steered by policymakers through grid price and upfront subsidies. Changes in regulations and incentive systems hence lead to changed consumption patterns and timing.

A European research project, CRISP (Critical infrastructure for sustainable power) claimed to provide "a new deal for the utilities" (Andrieu, 2005)[3]. Servatius (2012) framed this as a technocratic dream of blueprints for an efficient allocation of resources, which get newly interpreted by socio-technical approaches. Hayn (2015) discussed service level agreements and indicators in the context of capacity prices for demand flexibility on a residential level. Torriti (2012) considered different pricing strategies according to the activity or responsiveness level of demand response programme participants. Sernhed (2003) and Abaravicius (2006) discussed billing mechanisms, load management and reduction. Abaravicius (2007) focussed on scaling aspects for the purposes of electric load reduction. Furthermore, Sernhed (2016) illustrated and

3 http://www.crisp.ecn.nl/deliverables/D1.8.pdf

distinguished different interests in load management of customers and utilities across technical, economic, environmental, and social levels.

Melville (2017) framed the electric grid as a common pool resource. Being co-managed by a community required a system of rules for production and consumption, which in their approach focused on community accountability for individual consumption behaviour. Challenges arose in a peer-to-peer system, peculiarly not only due to the vertical, but also horizontal information exchange. The former is a plague shared by smart grid narratives, while the latter could be expected to be an incentive system on an eye-to-eye level. However, the P2P information exchange was not seen as a welcoming feedback system by this social system in the context of the UK.

While the before-mentioned are suitable for virtual utilities' energy management systems, our approach focuses on within-household dynamics and on coupling technical, social and economic factors. If aggregated, those could yield grid-friendly services and reduce the need for battery storage, grid usage, or backup capacities. Technologies to support the implementation of such services partly already are and would become more available at scale such that necessary assumptions, structures, and relations could be realised. Taking a bottom-up and micro-perspective with HH's potential to contribute to grid stability with GFMs, another set of assumptions is relevant. Our approach focuses on the technical versus social manageability and possibility to automatically manage adaptations. The knowledge mining or gaining of insights on needs, negotiability and potentials for providing GFMs takes place a priori and could but does not necessarily have to be supported by learning algorithms and analytics.

2. Paralleling Power Service Pricing with dynamic Tolling from Traffic Systems

A comparison of two infrastructure systems, namely traffic and electricity juxtaposes the regulation of power flow and traffic flow dynamics. At a first glance, time of use (TOU) pricing, dynamic pricing, fixed or dynamic load capping or adaptive and semi-automated versions thereof seem not to bear much resemblance or relevance across the different systems. Table 1 compares traffic flow and power flow systems with static or dynamic pricing options based on time or the grid state (traffic flow congestion). For the utilisation of supply, when grid constraints are disregarded, the grid is sometimes assumed to be a copper plate. In electric systems, a balance of supply and demand at any point in time and across the system is required for stability. In reality, however, electro-technical effects considering the topology (meshed, radial, etc.) of the grid network (non-linear, e.g. reactive flows, transient effects, etc.) are needed for ancillary services beside the "simple" supply-demand balance.

The second-last entry in the table conceptually refers to the theoretical possibility to employ additional lanes in traffic system resulting in the possibility of one direction being more served than the other. Such a scenario can flexibly alleviate the current situation by allocating capacity as needed. In theory, for the electric system, the same capacity is available in both directions, except if parts of the system do not allow feeding back. Through our adaptation mechanisms, this principle can be applied and more balance achieved through the employment of micro-flexibilisation, which can work in both directions, also increasing consumption, when suitable for the system.

Aspect	Traffic system	Power system
Desired switching behaviour	From peak to off-peak	Same, but possible across time scales
System costs / externalities	Social cost	Subsystem-specific
Individual costs incurred	Personal cost (time)	Individual supply security / instant availability
Time-based tariffs	Static congestion pricing	Time of use (TOU) tariffs
State-based tariffs	Dynamic pricing	Dynamic electricity tariffs
Traffic parameters to determine toll rate	Travel speed, occupancy and traffic delays	Supply-demand balance (or: residual load[4]), grid congestion, local grid balance
Distance based pricing	Miles driven (irrespective of traffic conditions)	kWh based pricing, without regard to when they were consumed
Cordon pricing	Area within a city	Could transfer logic to EV charging stations
Constant rates infrastructure service	Static tolling / pricing	Pay per kWh
Basis of service provision	Dynamic and moving (vehicle)	Stationary (household), device categories – vehicle parked / charging
Shifting scenarios	Demand shift (space, time)	Different options (consumption) over time of day or seasonal differentiation
Utilisation of supply	Roads are usable based on number of vehicles	Electric grid usable based on more complex interplay of various components
Start and stop / versions of a dynamic price	Single or multiple entry / exit points on the road network	Possible: different rates / pricing based on devices' effects on grid
Balance of flow directions	Flexible adaptation of lane directionality (e.g. USA, Spain)	System always needs to be in balance, less elastic
Location of connections	Entry / exit ramps on highway	Grid connection points of subsystems, indicating health across levels

Table 1: Overview paralleling dynamic tolling with dynamic power pricing from the bottom up.

3. Aggregation of electric Loads, Scaling Aspects and HH Effect onto Grid

Working from the demand in a time interval measured in A or W/time unit, and coupling this with the potential to adapt the demanded load, we provide a conditional tariff linked to the adaptability that is responsive to the current grid state. Opposed to this, standard DR models focus on loads to shift in time (technologically enabled through storage as a way for temporal decoupling) shift by reducing, curbing, or even shedding. Gobmaier (2013) takes the individual load profile (LP) that a controllable consumer would have without controls. His control mechanism takes market prices into consideration. The target of our contractual mechanism design approach reverses some of this logic, because the price is not a signal or (conscious behaviour-coordinating) trigger, but an output or a determinant for flexibility service valuation. The increasing dissemination of EVs can detrimentally impact onto grid stability (Gobmaier, 2013), which we show below. Whenever our sample rural HH[5] in Franconia, Germany, connects its EV, a drop in the local voltage value can be spotted instantly.

A possible mechanism, which we identified to find a measure for the grid state and the possible contributions to its stability was based on determining the local voltage of the external environment, without self-induced effects. That is, we mirror what would have been the voltage in the grid, had I not consumed (or equally produced / fed in) energy. Our heuristic was as follows: we calculated artificial voltage time series by taking an approximate empirical estimate of the local grid impedance (z = 0.2), multiplied with the irms value in each time instant, and added this to the measured vrms values to

4 Residual load in Germany refers to the load that is not covered by renewables and has to either be supplied by conventional sources or grid import.

5 Source: http://www.babelbee.org

yield the theoretical 'external' voltage without own contributions. Tariffs should be dependent upon the amount of (absolute or %) deviation from the permissible or recommendable bounds of the current voltage (maybe also frequency), where the voltage is a reflection of the local stability and the frequency reflects global stability. To make sure to incentivise behaviour that would not remunerate a HH or subsystem of the grid, which just has caused an imbalance just to correct itself, a technological device would be monitoring itself and its contribution to the voltage deviations. Appropriate monitoring strategies can be implemented in a smart meter.

Advanced power electronics already use similar strategies of "grid awareness". Tesla Motors uses a charging algorithm which ramps up the charging current while monitoring the resulting voltage drop. As soon as a certain lower threshold in local voltage is reached, the charging current is no longer increased in order to not overstrain the local infrastructure. One could employ a tariff to mix the old system based on kWh for uncritical grid states that shifts to another regime when voltage and/or frequency bounds and thresholds are reached. An incentive to participate in such a tariff scheme would be that for curtailing or additionally consuming in times required by the grid, one could receive a flat rate or unlimited charging in uncritical times. This strategy of tariff models coupled with the current physical conditions is very different to the one reported by in Böttcher and Heuer (2017), where cheaper weekend tariffs are compensated with more expensive weekday electricity. This could have a potentially destabilising effect on weekends depending on local infrastructure conditions, when (whirl)pools are heated disproportionately much. For an exemplary day in spring (April), where the EV was charged twice in that day, we calculated the difference in average empirical and theoretical voltage, as shown in Table 2 and Figure 1. One can see that both the maximum and minimum voltages occurred at times when the EV was being charged.

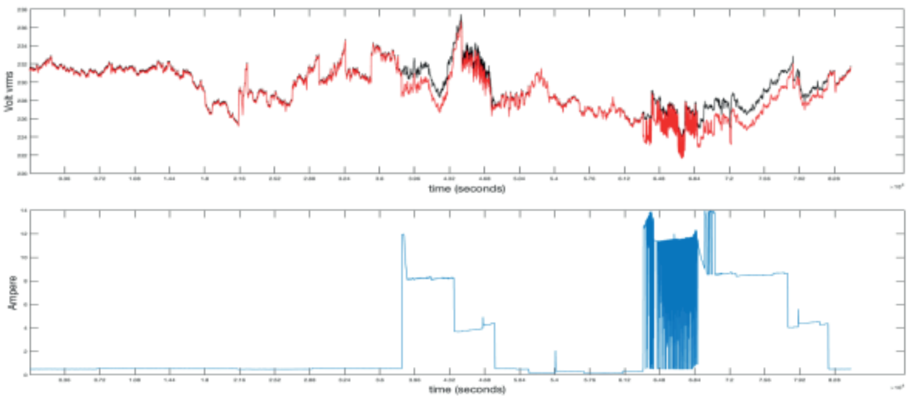

Figure 1: 2016/04/19 00:00-23:28, x-axis in sec: Empirically measured vrms (red), theoretical voltage (black) when calculating the effect of the irms (blue) electric current values due to the EV charging 'away'.

Grid parameter	Range (spring)	Average (spring)	Average (summer)	Average (autumn)	Average (winter)
Irms (Phae 1, mainly EV charging)	13.85 A	2.83 A	1.37 A	2.40 A	1.88 A
Vrms (empirical)	9.45 V	229.04 V	226,41 V	225,62 V	226,45 V
Vrms charging (current > 3A)		227.75 V	225,67 V	225,39 V	225,64 V
Vrms no charging (current <= 3A)		230.25 V	226,52 V	225,71 V	226,66 V
Vrms theoretical	9.46 V	229.61 V	226.68 V	226.10 V	226.83 V
Vrms theoretical charging		229.25 V	227,13 V	226,87 V	227,12 V
Vrms theoretical no charging		230.35 V	226,62 V	225,81 V	226,75 V

Table 2: Comparison (different seasons) of local voltage effect with(out) EV charging as basis for tariffs.

4. Conclusion, Outlook and Future Work

We described an approach for adaptive load management, combining social and technical factors. When concerned with the mutually beneficial interplay between grid and incentivising components, novel contracts with grid-sensitive tariffs and micro-level adaptation can become an integral part of future energy systems. We asked: what if other measures (related to the current grid state) of the temporal dynamics of electricity tariffs are considered? A parallel to traffic systems and dynamic tolling was drawn. If the current grid state were used as a basis for pricing and steering the adaptable loads, it might alleviate the burden of balancing the system further up. If aggregated, such contractually specified and technically controlled systems could provide balancing services to the next higher grid level. If implemented in a subsystem such as a village, an intentional community, or an off-grid system in an emerging country context, this could provide information on individual needs for storage, backup capacities, and appropriate connection conditions. Those results if aggregated allow conclusions about grid capacity. We will start with an adaptation of the load given the grid state, to balance it, taking currently available grid time series as an input. We plan to link this logic to an explicit grid simulation model from Germany in future.

These strategies could be used for decentralised markets as mediator, employing prices as regulator. The decisions about which pricing strategies to use in practice, who would offer such a service, how to allocate roles and which regulatory environments would be conducive for such implementations remain open questions. For a review of the interplay of different actors for demand response contracts and the evaluation of potentials on HH level, the EU project 'shift not drift' and He (2013b) serve as a good starting point; and for technical considerations of EU-wide potentials, the ecodesign task force on smart appliances (2017)[6]. Linking our tariff system into wider strategies and structures, creates elasticities in electric demand and is suitable for local prosumption scenarios. Even though no explicit information of the generation, demand and transmission lines were yet considered in our distributed strategy for contributing to grid health, the decentrally monitored current grid state still provides an indication of them. Based on the estimated indicators presented here, sophisticated tariffs can be negotiated and designed, or a very simple rule could be effected; namely to provide a base payment, e.g. as a reduction to the electricity bill for being a part of the system irrespective of the contributions. To reflect the success of the whole system, if it can be proven on higher subsystem levels that a stabilisation was effected, an additional bonus could be paid. In a context such as South Africa, where electricity theft is a reality, incentives to get connected and registered could be designed such that one could earn money or other values or services from being part of GFM service networks.

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Urban energy consumption and CO2 emissions by means of emergy and system dynamics model: Taking Beijing as a case

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Abstract

Cities play important roles in national economic development and population aggregation. At the same time, Cities contribute to half of the country’s energy usage and CO2 emissions. Therefore, analyzing the largest source of CO2 emissions will be helpful to reduce carbon emissions. This paper combines emergy theory and System Dynamics and try to make a progress in the problem. First, the boundary of ecological-economic system is defined, and then the system is divided into five parts, including agriculture, industry, service sector, residents’ consumption and transportation. Second, the emergy flows inside and outside of urban system are analyzed based on emergy synthesis theory, and then the emergy indices of urban eco-economic system are selected and confirmed. Third, the system dynamics model of emergy flows of urban ecological-economic system, which are divided into economic sub-model, population sub-model, resident sub-model, transportation sub-model and CO2 emission sub-model. The energy consumption and CO2 emission is forecasted and analyzed. Some policies of adjusting energy construction, such as reducing coal, increasing electricity and natural gas, are analyzed and their effects are discussed at the end of paper.

Keywords: urban eco-economic system; Emergy flow; System Dynamics model; energy consumption; CO2 emission

1. Introduction

In the past decades, some scholars were engaged into studying energy consumption and controlling the associated pollution gas and GHG emissions at the city level, with the classical energy-modeling approaches (Y. Y. Feng et al., 2013). Cities are widely open systems that always keep exchanging various materials, energies and information with the surrounding areas to support their development (Chen and Chen, 2006). Emergy analysis set up a bridge between urban ecosystems and economic systems (Odum, 1983; Odum et al., 1987). It treats the entire economic, social and ecological environment of the city as a whole (Hardin, 1986; Daily and Ehrlich, 1992; Meyer and Ausubel, 1999). Emergy flows analysis can analyze the flows of energy between various sectors in a city, as well as the exchange between socioeconomic system and ecological environment (Odum et al., 2000; Chen and Chen, 2009a). Emergy flows mainly focused on the transmission and transformation between internal and external resources, materials, even currencies in or out of urban systems (Brown and Ulgiati, 2001). However, it is difficult to study the city's feedback system and deal with the dynamic interaction among various factors in an urban eco-economic system by only emergy method. System dynamics is a right method to analyze the causal relationships among various factors and simulate urban eco-economic system. By computer simulations, it also can show future trends of the related factors in the systems. It has significant advantages in terms of dealing with complex systemic problems (Berling-Wolff and Wu, 2004; Arquitt and Johnstone, 2008). This paper will use system dynamics method to simulate the energy consumption and CO2 emission in urban eco-economic system, and construct its system dynamics model. With this model, we will analyze the energy consumption construction and its influence on CO2 emission, and future trends of energy consumption and CO2 emissions on different economic development levels. The innovation of this paper is using the system dynamics model to simulate urban emergy flow system, and then an emergy-flow dynamics model is established.

2. Data and Method

2.1 Study Area and Data

Beijing is an international metropolis with large population, high population density and rapid economic development. Beijing city is located at 115º7'-117 º4' E and 39º4'-41º6' N, and the area is 16,410.54 Km2, with six central set-up districts and two counties. At the end of 2016, the total population in Beijing was 21.148 million, and in which the floating population was 8.03 million. The density of population in the whole city was 1289 km2 per Capita, and it rise up to 9529 km2 per Capita in the central districts. In the recent 20 years, from 1995-2015, GDP growth rate of Beijing has been keep above 7.4%. And in order to keep the rapid economic growth and feed millions of local people, Beijing consumed lots of energy and emitted tons of CO2. Common problems of cities, such as the crowded population, busy traffic, air pollution and other problems also exist in Beijing city. Due to these characteristics, Beijing city is one of the most representative cities. Therefore, we take Beijing as the case area for this study. Most of data used In the paper, come from Beijing statistical yearbook (1998-2016)(Beijing Statistical Office,1998-2016) and China statistical yearbook (1998-2016) (National Bureau of Statistics,1998-2016).

2.2 Emergy analysis

The city's metabolic activities cannot be supported solely by the limited urban space within the administrative boundary, and require support from the city's external environment (Zhang et al.,2009). Firstly, based on the theory of emergy analysis, the flowing of emergy in Beijing city is analyzed to draw the emergy-flow diagram, as shown in Fig. 1. In the figure, the whole city is divided into six parts, including agriculture, industries, service sector, resident consumption and transportation. The energies in Beijing mainly include coal, coke, electricity, crude oil, gasoline, diesel, heat, natural gas. Most of electricity was from outside of Beijing, and others was generated by four power plants in Beijing, which burned coals or natural gas. All of heat in Beijing generated by power plants or some heating company. Urban residents not only provide the labor force, but also consume energy, and also generate or discharge CO2. The red dot lines indicate capital flows.

2.3 System Dynamics

System Dynamics (SD) is a system simulation methodology for dealing with the complex dynamic feedback. Due to its systems thinking and characteristics of visualization, it has been applied extensively to many research fields in which some system analysis methods usually are used, i.e., social systems, economic systems, ecological systems, resources and policies assessments systems(Dyson and Chang, 2005).

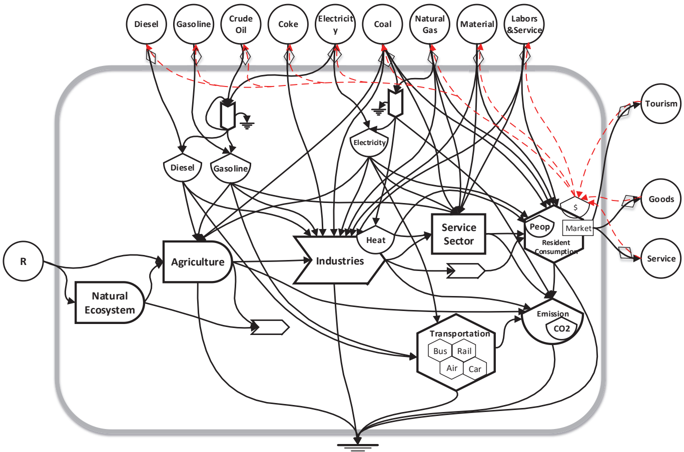


Fig. 1: Emergy flows diagram of urban eco-economic system

Within the regime of urban ecological and economic system, SD models have been applied to simulate the urban systems to research urban water management (Bagheri and Hjorth, 2007; Winz et al, 2009), urban energy consumption and environmental pollution (Feng et al, 2013; Vafa-Arani et al, 2014). However, not much attention has been paid to the research of urban emergy flows in an urban eco-economic system from the perspective of system dynamics. In this study, a system dynamics model according to the urban emergy flows diagram and emergy indices system was developed, which has been named as Emergy-flows SD model, for assessment and prediction of urban energy consumption and CO2 emission.

In order to verify the validity of the model, the Beijing's historical data of 1998-2013 is put into the model to predict the 2014 data. The error between the simulation value and the actual is less than 5%, which indicates the emergy-flow SD is valid. The results of validation are shown on table 1.

Table 1 Validation of the SD model in 2014

Items	Simulation result	Reference data	Relative error(%)
GDP*(Yuan)	1.10E+12	1.14E+12	-3.51
Total population(person)	2.15E+07	2.11E+07	1.90
Coal(tons)	2.18E+07	2.26E+07	-3.54
Natural Gas(tons)	9.32E+09	9.21E+09	1.19
Gasoline(tons)	1.61E+06	1.54E+06	4.55
Electricity()	6.15E+10	6.27E+10	1.91
Total Energy(seJ)	8.31E+18	8.20E+18	1.34
CO_2 (tons)	1.33E+22	1.28E+22	3.91

* The GDP means real GDP based on the market prices level in 1995

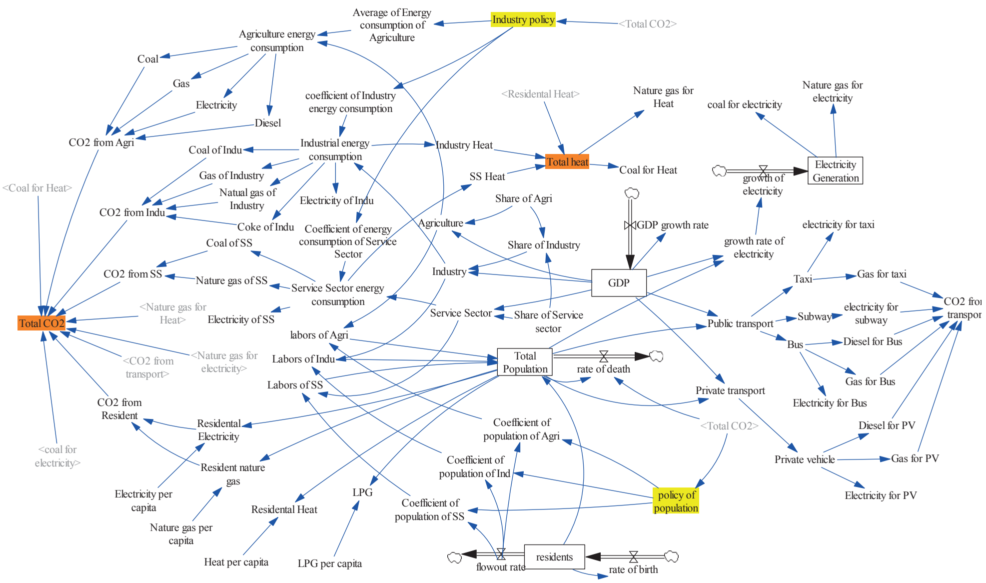


Fig. 2 Emergy-flow SD model of urban energy consumption and CO2 emission

3 Results and discussion

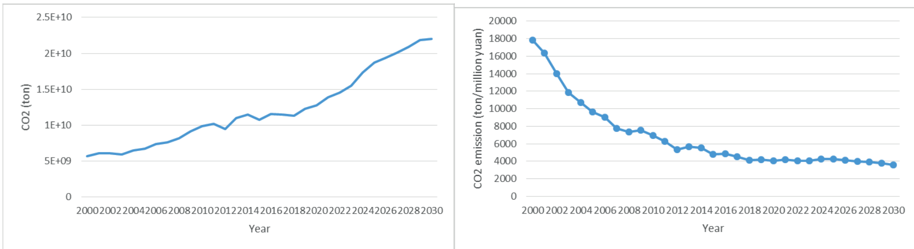
The growth rate of economy in Beijing during 2015-2030,will be assume to be 7%; The growth rate of registered population in this scenario will be set at 0.26%; while the floating population in the scenario will depend on the GDP growth rate, according to the equation in the model. As shown in the Figures below the data from 2000 to 2014 are real, and the data from 2015-2030 are simulated by the SD model.

3.1 Relationship between CO2 and GDP growth

Because of rapid growth of GDP and population in Beijing, CO2 emission will obviously raise, as shown in Figure 3(a). In the graph, the growth of CO2 showed an exponential growth trend. From Figure 3(b) can be seen, the CO2 emission per GDP decreased year by year, but the trend gradually slowed down. The main reason is that the energy consumption per GDP is reduced to make the CO2 emissions decreased year by year.

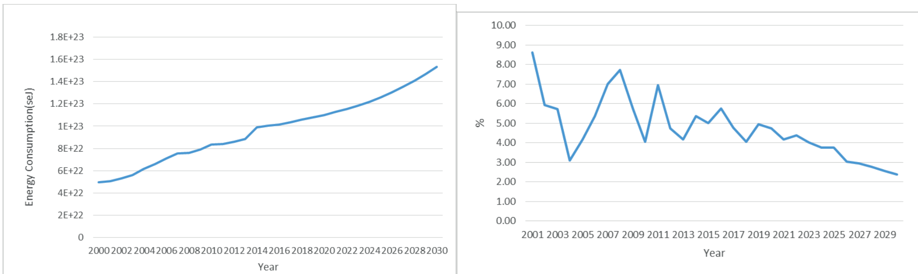
3.2 energy consumption

Beijing's economic development and people's living needs a lot of energy. As can be seen from Figure 4(a), the energy consumption of Beijing City is rising. And it can be seen from Figure 4(a), the total energy consumption in 2016-2030 compared to the past fifteen years showed a trend of rapid growth. The energy consumption per GDP values are falling, from 1.2 in 2000 down to 0.2 or so in 2030. But from 2016 to 2030, the decline in energy consumption per unit of GDP will slow down. And can be seen from Figure 4(b), the declining ratio of energy consumption per GDP during forecast period decrease significantly.



(a) CO2 emissions in Beijing (b)CO2 emission per million yuan GDP

Fig. 3 CO2 emissions and CO2 emissions per million yuan GDP in Beijing from 2000 to 2030



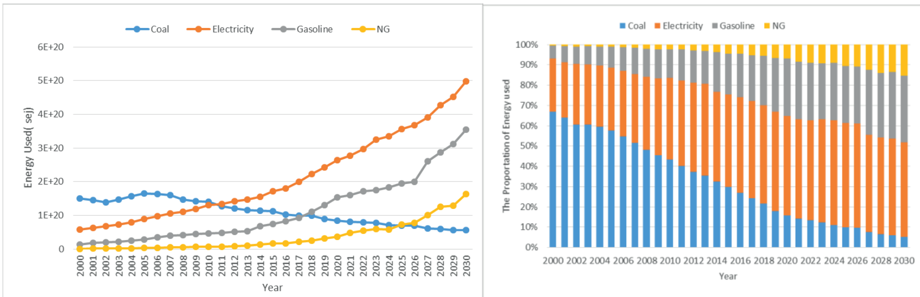
(a) Energy consumption (b) Declining ratio of energy consumption per GDP

Fig. 4 Energy consumption and declining ratio of energy consumption per GDP in Beijing

3.3 energy construction's influence on CO2 emission

The following figure is the four most important energy in Beijing city in 2000 to 2030. Due to the adjustment of energy structure of Beijing, proportion of coal obviously reduce, and on the contrary, other energy, such as natural gas and gasoline, consumption growth of them are very rapid. However, the decline of coal is not the main reason for the reduction of CO2 emission per GDP in Beijing City. The main reason is to use large number of electricity. Because most of Beijing's electricity comes from outside, and the generation of electricity by the power plants in Beijing keep stable, so the additional demand for electricity in the next 15 years is to be met by the power plants, which are outside of Beijing.

Due to the units of four energy is not uniform, in order to be able to more clearly observe the changes in the proportion of energy structure, the city's four major energy sources into Emergy. From Figure 5 can be seen more clearly, the proportion of Beijing's future energy, electricity, gasoline, natural gas accounted for an increasing proportion, while the proportion of coal is getting smaller. The emergence of this phenomenon reflect the policies are effective, such as the promotion of electric vehicles in Beijing in recent years, relocation of the steel plant in Beijing. However, due to the increase of population and the expansion of urban functions in Beijing, the demand for gasoline is not reduced, instead of a significant increase. But overall, due to the extensive use of electricity, and power generation is not in the city of Beijing, the growth of CO2 emissions slowdown in Beijing. However, China's electricity is mainly from thermal power, so from the whole life cycle of electricity, CO2 emission will not decrease, but because of the rapid economic and population growth, making the CO2 emissions increased.



(a) Emergy used in four kinds of main energy (b) proportion of Emergy used of four types

Fig. 5 Emergy used and proportion of four kinds of main energy

4. Conclusion

In the paper, System Dynamics is used to simulate the urban eco-economic system based on emergy analysis methods. External and internal emergy flows of urban eco-economic system are analyzed, and emergy indices system of Beijing city is built. After analyzing causal relationship of factors in urban system, an emergy-flow System Dynamics model with five sub-models is set up. In this study, we combine System Dynamics and Emergy Synthesis for modelling the comprehensive, dynamical, interactional urban eco-economic system, and get some interesting conclusions, which are difficult to be obtained only by single method, whatever emergy analysis or System Dynamics:(1) Due to the rapid economic development and population growth in Beijing, the total amount of energy consumption and CO2 emissions in Beijing will be significantly increased in the next 15 years. (2) The CO2 emission of unit GDP of Beijing city was significantly decreased, the main reason is the decline in the level of energy consumption per GDP, and the adjustment of energy structure. (3) The coal consumption in Beijing is significantly reduced, and it is replaced by gasoline, natural gas and electricity. And because of the wide use of power, Beijing's CO2 emission per GDP have a obvious decline. But this decline is at the expense of increasing the level of CO2 emissions in other areas.

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What causes PM2.5 pollution? Cross-economy empirical analysis from socioeconomic perspective

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Abstract

Is it true that, as the mainstream intuition asserts, urbanization and industrialization are the two main socioeconomic drivers of PM2.5? How do the two trends affect PM2.5 emission? This paper quantitatively analyzes the socioeconomic drivers of PM2.5 through assessment on Stochastic Impacts by Regression on Population, Affluence and Technology (STRIPAT), based on the panel data of 70 developing countries over 2001-2010. The average levels of PM2.5 pollution in the samples are calculated using remote sensing data, which overcomes the difficulties that developing countries' lack of PM2.5 monitors and that point data cannot reflect the overall level of PM2.5 pollution in an economy on a large scale. Squared terms of income and urbanization and their cross term are included in the regression models respectively to analyze the possible heterogeneity income and urbanization caused on PM2.5 emissions in different development stages. The results show that income, urbanization and service sector have significant impact on PM2.5 pollution. Specifically, on the one hand, income has a positive effect on PM2.5 all the time but the effect decreases as the level of urbanization or income goes up. On the other hand, an inverted U relationship exists between urbanization and PM2.5, in which PM2.5 pollution positively correlates with a low level of income or urbanization but negatively at a high level. Policy recommendations from the perspective of macro-level social and economic regulation are provided for developing economies to reduce PM2.5 pollution.

1. Introduction

According to a global-scale estimate, PM2.5[1] concentrations are high in densely populated areas that are undergoing fast urbanization and industrialization (Van et al., 2010). Given the fact that many developing countries suffer from PM2.5 pollution, it seems plausible that industrialization and urbanization are the main drivers of PM2.5 pollution, which is the mainstream view. However, this view lacks empirical tests and needs to be examined through quantitative analysis.

There is large body of literature studying socioeconomic driving forces of air pollution, but most of them focused on carbon dioxide, while others targeted sulfur oxides, oxides of nitrogen or PM10. As for PM2.5, there have been plentiful studies focusing on source apportionment, including both natural processes and human activities, from a micro-level perspective (Kaur et al., 2007; Belis et al., 2013; Pui

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[1] Fine particles with a diameter of 2.5 micrometers or less.

et al., 2014; Karagulian et al., 2015; Li, X. et al., 2015; Liang et al., 2016), while its socioeconomic driving forces were almost ignored. Only recently, few studies came to realize the importance of the macro drivers of PM2.5 pollution. Xu and Lin (2015a) and Xu et al. (2016) analyzed the impact of income, energy intensity, urbanization, private vehicles and coal consumption on PM2.5 pollution with a panel dataset of 29 provinces in China over 2001-2012.

In order to find a reasonable explanation for the severe PM2.5 pollution in developing countries to assist relevant policy design, it is urgent to quantitatively analyze the socioeconomic driving forces and macro mechanism. Thus, this study investigates the socioeconomic driving forces of PM2.5 in developing countries, using the Stochastic Impacts by Regression on Population, Affluence and Technology model (STIRPAT), on a panel dataset of 79 developing countries over the period 2001-2010. Since many developing countries lack ground-based monitoring PM2.5 data, this paper uses the global satellite observations of PM2.5 concentrations over 2001-2010, provided by Socioeconomic Data and Applications Center (SEDAC) [2], and socioeconomic data of 79 developing countries to analyze the driving forces and provide a quantitative basis for PM2.5 control.

2. Material and Methods

2.1 Indicator for the socioeconomic drivers and sample

The explanatory variables are population size (*POP*), urbanization level (*URB*), GDP per capita (*GDPPC*), percentage of value added of industry in GDP (*IND*), percentage of value added of service in GDP (*SER*) and energy use per GDP (*ERG*).

The samples in this paper are categorized into lower income, lower middle income and upper middle income countries according to World Bank country classification based on gross national income per capita in 2005[3], considering that the dataset covers a time span of 2001-2010. There are 79 countries without missing observations over the period 2001-2010.

2.2 Empirical model and methodology

The regression is based on the STIRPAT model developed on the basis of IPAT identity and ImPACT identity. The STIRPAT model is as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{2}$$

Coefficients can be estimated using multivariate regression with the variables in logarithmic form. Coefficient *b*, *c* and *d*, are the elasticities of *P*, *A* and *T*, respectively. Thus,

$$\ln I_i = \ln a + b\ln P_i + c\ln A_i + d\ln T_i + \ln e_i \tag{3}$$

in which the environmental impact *I* denotes annually average PM2.5 concentrations at country level. Population factors (*P*) include total population (*POP*) and the proportion of urban population in total population (*URB*). Affluence (*A*) is represented by GDP per capita (*GDPPC*). Technology (*T*) [4] is disaggregated into industrial structure (*IND*, the percentage of value added of industry in GDP, and *SER*, the percentage of value added of service in GDP) and energy intensity (*ERG*, energy use per GDP). Moreover, there may be country specific effect due to different geographic factors, and time specific effect due to fluctuations of climate, etc. Thus, country dummy variables C_i and time dummy variables

[2] SEDAC, the Socioeconomic Data and Applications Center, is one of the Distributed Active Archive Centers (DAACs) in the Earth Observing System Data and Information System (EOSDIS) of the U.S. National Aeronautics and Space Administration.

[3] http://siteresources.worldbank.org/DATASTATISTICS/Resources/OGHIST.xls

[4] In the STIRPAT model, T includes all factors other than P and A (York et al., 2003). In this paper, T is decomposed into industrial structure and energy intensity.

Y_t are included in the specified regression models and respective test statistics are calculated to examine whether these dummy variables are appropriate.

First, linear effects are considered. Model 1 include the linear terms *POP*, *GDPPC*, *URB*, *IND*, *SER* and *ERG* in the logarithmic form as well as country dummy variable *C* and time dummy variable *Y*. The model is as follows.

Model 1:

$$\ln I_{it} = \beta_0 + \beta_1 \ln POP_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 \ln URB_{it} + \beta_4 IND_{it} + \beta_5 \ln SER_{it} + \beta_6 \ln ERG_{it} + C_i + Y_t + u_{it} \quad (4)$$

In order to test multicollinearity among the variables in Model 1, variance inflation factors (VIFs) are calculated, and we can safely conclude that multicollinearity does not exist. However, Model 1 fails to express the nonlinear effects of income and urbanization on PM2.5 concentrations. In order to analyze such potential effects, Model 1 is augmented with the quadratic term of ln*GDPPC* and ln*URB* respectively as follows:

Model 2:

$$\ln I_{it} = \beta_0 + \beta_1 \ln POP_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 \ln URB_{it} + \beta_4 IND_{it} + \beta_5 \ln SER_{it} + \beta_6 \ln ERG_{it} + \beta_7 [\ln GDPPC_{it}]^2 + C_i + Y_t + u_{it} \quad (5)$$

Model 3:

$$\ln I_{it} = \beta_0 + \beta_1 \ln POP_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 \ln URB_{it} + \beta_4 IND_{it} + \beta_5 \ln SER_{it} + \beta_6 \ln ERG_{it} + \beta_8 [\ln URB_{it}]^2 + C_i + Y_t + u_{it} \quad (6)$$

Next, the interaction between the two nonlinear variables should be calculated in case of strong correlation in between. According to our calculation, the correlation coefficient between ln*GDPPC* and ln*URB* is the only one above 0.5 among all independent variables (0.77). Thus, Model 1 is augmented with the cross term of ln*GDPPC* and ln*URB* as follows[5]:

Model 4:

$$\ln I_{it} = \beta_0 + \beta_1 \ln POP_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 \ln URB_{it} + \beta_4 IND_{it} + \beta_5 \ln SER_{it} + \beta_6 \ln ERG_{it} + \beta_9 [\ln GDPPC_{it} * \ln URB_{it}] + C_i + Y_t + u_{it} \quad (7)$$

If the results of Model 4 are consistent with the ones of Model 2 and Model 3, then the results of Model 4 are to be chosen for further discussion; otherwise the results of Model 2 and Model 3 are discussed further.

There is also a need to test the possible existence of country specific effect, time specific effect and other potential problems such as heteroscedasticity, cross sectional dependence and serial correlation. All test results are listed in Table 3.

Table 3 Test results of the models

	Model 1	Model 2	Model 3	Model 4
Hausman Test	$\chi^2(15)$=5.91	$\chi^2(16)$= 122.31***	$\chi^2(16)$= 140.27***	$\chi^2(16)$= 119.53***

[5] In models with X_1, X_2 and their cross term X_1X_2, the correlation between X_1X_2 and X_1 (or X_2) can be high, but this does not violate the assumption of no multicollinearity and the analysis of interaction effects, unless the correlation is so high that the software cannot calculate the standard error (Jaccard and Turrisi, 2003).

F Statistics (Time Fixed Effect)	F(9,696)=11.71***	F(9,695)= 9.60***	F(9,695)= 10.70***	F(9,695)= 9.71***
Heteroskedasticity	χ^2(79)=3402.79***	χ^2(79)= 5238.02***	χ^2(79)= 3822.50***	χ^2(79)= 4333.10***
Robust Hausman Test	χ^2(6)=25.96***	χ^2(7)= 33.09***	χ^2(7)= 24.39***	χ^2(7)= 30.83***
Robust F Stastics (Time Fixed Effect)	F(9,78)=18.52***	F(9,78)= 14.63***	F(9,78)= 17.05***	F(9,78)= 15.71***
Cross-sectional dependence[a]	0.363(0.7170)	0.362(0.7175)	0.365(0.7153)	0.326(0.7443)
Serial correlation[a]	F(1,709)=1.23(0.27)	F(1,709)=1.60(0.21)	F(1,709)=1.53(0.22)	F(1,709)=1.83(0.18)

[a] Statistical significance is indicated by: ***p<0.01, **p<0.05, *p<0.1
[b] p-value in parentheses

As in Table 3, the results of modified Wald test indicate the presence of heteroscedasticity in all four models. Robust Hausman test results and robust F test results prove the existence of country specific effect and time specific effect. Thus, the country dummy variables C_i and time dummy variables Y_t are included in all four models. In cross section dimension, the results of Pesaran test do not reject the null hypothesis of cross sectional independence. In time series dimension, the results of the test proposed by Wooldridge (2002) do not reject the null hypothesis of no serial correlation. Given the presence of heteroscedasticity, cluster-robust standard errors at country level are used (Rogers, 1994).

3. Results

3.1 Results of models 1-4

The regression results of the four models are listed in Table 4.

Table 4 Regression results of all four models

	Model 1	Model 2	Model 3	Model 4
ln*POP*	0.325 (1.93)*	0.112 (0.58)	0.287 (1.73)*	0.139 (0.72)
ln*GDPPC*	0.191 (2.23)**	1.323 (3.28)***	0.185 (2.18)**	0.925 (3.64)***
ln*URB*	0.195 (1.10)	0.098 (0.57)	2.555 (2.35)**	1.699 (2.98)***
ln*IND*	0.076 (1.18)	0.085 (1.39)	0.080 (1.27)	0.089 (1.44)
ln*SER*	0.173 (2.14)**	0.141 (1.94)*	0.169 (2.20)**	0.161 (2.15)**
ln*ERG*	0.076 (1.27)	0.094 (1.57)	0.085 (1.43)	0.099 (1.69)*
$[\ln GDPPC]^2$		-0.064 (-2.80)***		
$[\ln URB]^2$			-0.328 (-2.26)**	
[ln*GDPPC**ln*URB*]				-0.189 (-2.91)***
Constant	-6.793(-2.06)**	-7.826(-2.41)**	-10.311(-2.93)***	-9.625(-2.98)***
Year Dummies	Yes	Yes	Yes	Yes
Country Dummies	Yes	Yes	Yes	Yes
Observations	790	790	790	790
Groups	79	79	79	79

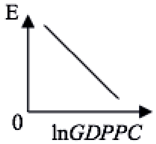
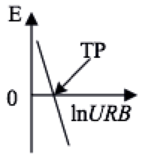
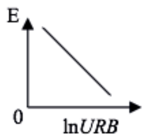
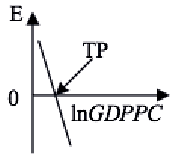
[a] Statistical significance is indicated by: ***p<0.01, **p<0.05, *p<0.1
[b] t statistics in parentheses
[c] Standard errors are clustered at country level

3.2 Model selection based on the results

In this section, the four models are compared and chosen for further discussion according to their regression results.

As shown in Table 4, all quadratic terms in Model 2 to Model 4 are significant, indicating the existence of nonlinear impact. Thus Model 2 to Model 4 are chosen for further discussion. The comparison of Model 2, Model 3 and Model 4 focuses on the trend of elasticity and whether a turning point exists. The calculation results of elasticity and turning point are listed in Table 5.

Table 5 Comparison of *GDPPC* elasticity, *URB* elasticity[6] and turning point in Model 2, 3, and 4

Model	Model 2	Model 3	Model 4 [a]	
Variable	*GDPPC*	*URB*	*GDPPC*	*URB*
Elasticity	$\beta_2+2\beta_7\ln GDPPC$	$\beta_3+2\beta_8\ln URB$	$\beta_2+\beta_9\ln URB$	$\beta_3+\beta_9\ln GDPPC$
Estimates of elasticity	$1.323-0.128\ln GDPPC$	$2.555-0.656\ln URB$	$0.925-0.189\ln URB$	$1.699-0.189\ln GDPPC$
Range of elasticity	0.505→0.015	0.825→-0.428	0.427→0.065	0.491→-0.233
Turning Point	$-\beta_2/2\beta_7$	$-\beta_3/2\beta_8$	$-\beta_2/\beta_9$	$-\beta_3/\beta_9$
Estimates of turning point	$\ln GDPPC^*=10.336$	$\ln URB^*=3.895$	$\ln URB^*=4.894$	$\ln GDPPC^*=8.989$
95% confidence interval for turning point	(8.532, 12.033)	(3.374, 4.416)	-[b]	
Diagram of elasticity [c]				
Trend in PM2.5 concentrations	Ceteris paribus, PM2.5 concentration increases as *GDPPC* increases at any income level.	Ceteris paribus, at low level of urbanization, PM2.5 concentration increases as urbanization rate increases; after reaching the turning point, PM2.5 concentration decreases as urbanization rate increases.	Ceteris paribus, PM2.5 concentration increases as *GDPPC* increases at any level of urbanization.	Ceteris paribus, at low income level, PM2.5 concentration increases as urbanization rate increases; at high income level, PM2.5 concentration decreases as urbanization rate increases.

[a] In model 4, the variable in the expression of *GDPPC* elasticity is ln*URB* and thus ln*URB* is depicted on the horizontal axis in the diagram of *GDPPC* elasticity. It is similar for *URB* elasticity.
[b] The 95% confidence intervals of *GDPPC* elasticity and *URB* elasticity are shown in Appendix A.1.

[6] In the model ln $I = a + b$ ln A, the A elasticity of impact (not log A elasticity of impact) can be calculated by taking partial derivative with respect to log A. Similarly, the *GDPPC* elasticity and *URB* elasticity are calculated here.

[c] The variable in the expression of elasticity is depicted on the horizontal axis. TP stands for turning point and E stands for elasticity.

The results of Model 4 are consistent with the results of Model 2 and Model 3, since Model 2 and Model 3 display only part of the nonlinear effect. Thus, the following discussion is derived from the results of Model 4.

3.3 Results based on model 4

Three key points in Model 4 are summarized as follows.

Among all factors studied, the impact of total population and industrialization on PM2.5 concentration is not so obvious, the impact of *GDPPC*, *URB* and *SER* is significant, while the impact of energy consumption per unit GDP is statistically insignificant on a 5% significance level.

Second, there is a positive correlation between income and PM2.5 concentration, but the effect of income on PM2.5 decreases as the level of income and urbanization goes up, according to the regression results of the squared term of *GDPPC* and the cross term.

Similarly, an inverted U-shaped relationship between urbanization and PM2.5 concentrations exists, according to the results of the squared term of *URB* and the cross term. At low level of income or urbanization, *URB* has positive correlation with PM2.5 concentrations but negative at a high level of income or urbanization.

4. Conclusion

This paper analyzes socioeconomic driving factors of PM2.5 pollution in 79 developing countries from 2001 to 2010 by environmental driving model STIRPAT. The PM2.5 pollution level in the paper comes from satellite remote sensing data, which makes up for the lack of surface observation, and overcomes the defect that point data cannot describe the overall situation of large-scale space.

The study finds that income, urbanization and service sector are the key driving factors of PM2.5 pollution level. The details are as follows:

(1) Income Level: The positive effect of income on PM2.5 concentration is ever-present. Theoretically, the inverted U-shaped curve relation might exist between income and PM2.5 concentration, but all the developing countries in this study are on the left side of the turning point. This implies that the technical effect of economic growth on environment cannot make up for the proportion effect in these countries during the observation period of the study.

(2) Urbanization: Two inverted U-shaped curve relationship exists between urbanization and PM2.5 concentration. The result shows that the increasing urbanization will reduce PM2.5 pollutant emission after urbanization level or income level reach their turning points. The study finds that urbanization's positive effect on environment can be attributed to scale economy of industrial pollution control, optimization of household energy structure and effectiveness of environment protection and control.

(3) Service sector: Service sector is causing PM2.5 pollutant emission. First, transportation and catering are parts of service sectors which are both notable factors of PM2.5 pollution. Second, service sector is scattered in terms of energy consumption and pollutant emission, so it is difficult to obtain economies of scale in energy consumption reduction and pollution control for service sector.

However, the conclusion of this paper does not imply that the pollution of PM2.5 will reduce spontaneously with the advancement of economic level and urbanization. The PM2.5 pollution problems in developing countries should be addressed rationally and positively.

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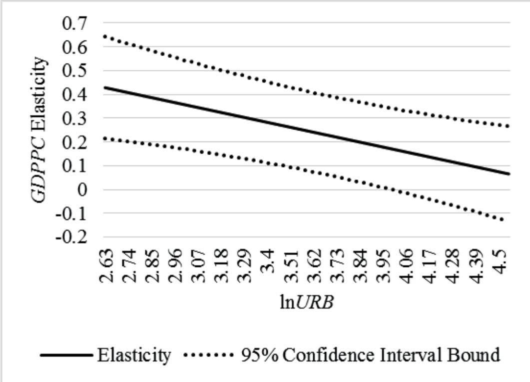
Appendix

A.1: 95% Confidence Interval of *GDPPC* Elasticity



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Lessons from European Energy Research and Energy RIs: Towards a European Science of Research Organizations?

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Abstract

Over the past decade two simultaneous developments have occurred in the European science landscape. One, as a key pillar in the innovation policy of The European Union attempts have been made to foster the development of research infrastructures (RIs). The focus on single large R&D projects, sometimes called Big Science, beyond the capacities of networks of ordinary research laboratories has been aided by the European Strategy Forum on Research Infrastructures (ESFRI) and through national RI-roadmaps with the aim of delivering European science on a world-class level. Many studies have shown how an internationalization of European research organizations have occurred over the same time span. Research organizations, both public research centres (PRCs) and research technology organizations (RTOs), have expanded beyond their geographical origin, delivering specialized expertise, and successfully attracted European funding from Framework Programmes and Horizon2020.

Drawing on data from the European Union Cordis-database, this paper examines the funding of energy projects over four years (2013-2017), and documents the key roles of research organizations within these projects. The empirical data will be used to map the participating research organizations across fifteen different energy subsectors of energy research as defined by the latest ESFRI-landscape analysis, showing both the key organizations in energy research as a whole and the key organizations within each field. The study also examines national strongholds, and the major differences which can be observed between different countries in terms of the relative strength of research organizations vis-à-vis other entities like universities.

Furthermore, this paper discusses the central role of research organizations in a future landscape of research infrastructures. We expect specialized and internationalized research organizations to be center stage of a European innovation policy promoting increasingly specialized and internationalized RIs. The paper shows how this is already the case in the field of nuclear fission where two research organizations have both participated as partner in more than 50% of all funded projects kicking off during the analyzed timeframe.

1. Introduction

Europe cannot meet its proposed radical energy transformation in an economically, socially and environmentally sustainable way without the Schumpeterian trilogy of invention, innovation and diffusion. For any discussion of possible energy futures, it is therefore of interest to assess the state of the field of energy research, development and innovation, to examine the roles of the actors involved, and to explore the observable trends shaping possible development innovation pathways.

We are in this study interested in two simultaneous movements which has occurred within the general science landscape of the European Union over the past decade and its effects on European energy research. First, following the 2010-recommendations of the interim evaluation of the European Union's 7th Framework Programme (European Union, 2017a), more attention has been provided for high quality Research Infrastructures or so-called Big Science[1]. Secondly, European Research Organizations (RO's) of varying shapes and forms have increasingly become internationalized, and recent studies have shown their changing roles within European, national and regional science, technology and innovation.

This study provides a descriptive analysis of Research Organizations'[2] participation in energy projects under EU's Horizon 2020-program in the period of 2013-2017. We identify the most important European RO's in Europe in various fields of energy research, showing both a relatively coherent set of dominant European RO's and heterogeneity in the influence of RO's across national innovation systems.

2.1. Big Science, Research Infrastructures and Integrating Activities

Investments in research and innovation is considered to be a key driver for economic growth and strengthened international competitiveness in the European Union (European Union, 2017b). The ongoing Horizon 2020-programme includes total funding of nearly €80 billion[3]. There is already talk of significantly increasing the budget even further for the next framework science programme (European Union, 2017a).

Part of the budget goes to large-scale research infrastructure projects. EU member countries together spend around €10 billion annually on running shared research facilities (Autio, 2014). The Horizon 2020 Programme includes an additional €2.5 billion between 2014 and 2020, including financing for so-called '*integrating activities*'[4]. The EU now have several avenues for scientific cooperation (European Union, 2017b). The European Strategy Forum for Research Infrastructures (ESFRI)

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[1] This analysis has been informed by the authors' participation in the RISCAPE-project (www.riscape.eu) which analyses European Research Infrastructures in the International Landscape. RISCAPE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730974.
[2] Research Organizations (RO's) in the terminology of this analysis include both Public Research Organizations (PRO's), private Research and Technology Organizations (RTO's) and other elements (for a brief typology of RO's see e.g. Sanz-Menendez, 2011).
[3] https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020
[4] http://www.esfri.eu/ri-projects

has published a roadmap biannually since 2006. Ten Joint Programming-initiatives and 48 ERA-Cofund initiatives have been launched. In addition, a new legal entity, ERIC, has been created for European Research Infrastructures.

Research on outputs suggests that Europe is indeed moving towards an integrated European Research Area (Scherngell & Lata, 2012), and if the future science and innovation policy of the European Union continues along the path laid out in the transition from previous Framework Programmes to Horizon 2020, then one should expect policies with even more attention towards coordination and integration in the future. This has been pointedly been coined as transitioning from “Science in Europe” to “European Science” (Wedlin & Nedeva, 2015).

2.2. The changing roles of Research Organizations

A number of studies have described the growing importance of Research Organizations over the past decade. The role of the Research Technology Organizations (RTO’s) as technology transfer agents aiding national or regional industrial companies have attracted particular academic interest (e.g. Fritsch & Schwirten, 2006; Garrison et al., 2010; Tann et al. 2013; Jansen et al., 2015; Vivas, 2016). This corresponds precisely to the core role many European RTO’s were created to fulfill with the raison d’etre being the aiding of the Schumpeterian dimension of diffusion. This is an important role, as diffusion (the spread of new technology across new markets) is the most important element in increasing competitiveness (cf. Stonemann & Dideren, 1994)[5]. Unsurprisingly, the role of RTO’s as a driver of Smart Specialization has also received considerable interest recently including from representatives of the European Union (Charles & Stancova, 2015).

It is by now well described how Research Organizations have undergone internationalization (Zacharewicz et. al, 2017; Charles & Stancova, 2015). Internationalization provide new avenues of funding strengthening the Research Organizations (in some case internationalization has been driven by need due to declining national opportunities), and it increases the ability for RO’s through their networks and research collaborations to facilitate the access to global knowledge for their original clients and stakeholders.

As RO’s transcends their geographical origins and effectively compete on the same markets, one might expect those organizations capable of adapting to new conditions (cf. Cruz-Castro et al., 2012; Loikkanen et al, 2011) to grow comparatively stronger. A hypothesis along these lines would be that internationalization can be followed by a consolidation of RO’s. This hypothesis seem even more possible in a landscape of integrating activities where strong RO’s can create mutual networks along several different subsectors simultaneously.

[5] Zacharewicz et al, 2017 provides an interesting discussion of the internal concern among RTO’s that the expanded roles of the organizations must not be at the expense of this classic role of regional technology transfer agent.

3. Analysis of Energy Projects in Horizon 2020

For this analysis a database has been created with all energy projects publicly available in the CORDIS-database across fifteen different subsectors of the energy field. CORDIS is the European Commission's primary portal for results of EU-funded research projects[6]. The typology of fourteen different subsectors is based on the landscape analysis in the 2016 European Strategy Forum for Research Infrastructures (ESFRI)[7]. The database covers all projects initiated between 1.5.2013 and 1.6.2017[8].

For the analysis, the description in CORDIS of 'Research Organization' (compared to e.g. 'Public Body') has been utilized as the operationalization of RO's.[9] A total of 548 Research Organizations appear in the dataset across a total of 1 732 projects.

3.1. Country analysis

The database illustrates major differences across countries, both in terms of number of participating Research Organizations and in the subsectors in which a given country's has received the largest amount of Horizon-funding. Unsurprisingly the biggest members of EU – Germany (73 RO's), France (44 RO's), Spain (78 RO's), Italy (54 RO's) – provides the largest numbers of ROs with participation in most projects. Unsurprisingly, much of the academic literature on Research Organizations have also concerned these countries, especially related to the experience of Spain.

In certain countries Research Organizations attracts almost no funding despite strong national energy research pedigrees. This is the case for e.g. United Kingdom (bar carbon capture and storage-projects), Denmark and Ireland. This can possibly be explained by the different positions of RO's within national systems of innovation.[10] There are various possibilities to organize Triple Helix or Quartet Helix (see Santonen, Kaivo-oja & Suomala, 2014).

3.2. Top Energy Research Organizations

We have identified the Research Organizations which have attracted the largest amount of funding across the specified subsectors. Table 1 describes the 20

[6] http://cordis.europa.eu/home_en.html

[7] http://www.esfri.eu/roadmap-2016. Note that the ESFRI-landscape analysis is divided to 17 different sections, but we have not found it possible to operationalize "materials / computing" or "impacts" in meaningful ways.

[8] The plan is to update for a full five years of projects at a later stage of the project.

[9] There are a few exceptions where organizations used by others as case studies of RO's has been coded by the authors as RO's despite other descriptions in CORDIS. Please contact the authors for more details.

[10] To examine this point and the consequences here of, a comparative analysis of the differences between Nordic countries appears particularly interesting. Despite a slightly smaller population, Finnish research organizations appears to attract more about ten times more energy research funding from Horizon 2020 than Danish RO's, while Norwegian RO's with an even smaller population attracts considerable more funding on top of that.

Research Organizations in Europe which have attracted the most funding, and then those subsectors where the respective organizations is among the top 5 Research Organizations in funding received.

Table 1. Top Energy Research Organizations in Europe.

Name	***Country***	***Among top 5 ROs in received funding***
Fraunhofer	Germany	Bioenergy, Carbon Capture and Storage, Concentrated Solar Power, Energy Efficiency in Industry, Energy Storage, Fuel Cells and Hydrogen, Geothermal, Ocean Energy, Photovoltaics, Smart Cities, Smart Grids, Wind Energy
CEA	France	Energy Efficiency in Industry, Energy Storage, Fuel Cells and Hydrogen, Nuclear Fission, Nuclear Fusion, Photovoltaics, Smart Grids, Wind Energy
SINTEF	Norway	Carbon Capture and Storage, Concentrated Solar Power, Energy Storage, Hydropower, Ocean energy, Wind Energy
CNRS	France	Carbon Capture and Storage, Concentrated Solar Power, Energy Storage, Fuel Cells and Hydrogen, Hydropower, Nuclear Fission, Nuclear Fusion
Tecnalia	Spain	Energy Efficiency in Industry, Geothermal, Ocean energy, Smart Cities, Smart Grids, Wind Energy
Helmholz Association	Germany	Energy Storage, Geothermal, Nuclear Fission, Nuclear Fusion,
VTT	Finland	Fuel Cells and Hydrogen, Smart Grids
CIEMAT	Spain	Bioenergy, Nuclear Fission, Wind Energy
ECN	Netherlands	
ENEA	Italy	
CNR	Italy	Geothermal
AIT	Austria	Smart Cities, Smart Grids
Max-Planck-Gesellschaft	Germany	Bioenergy, Fuel Cells and Hydrogen
CSIC	Spain	
SCK-CEN	Belgium	Nuclear Fission, Nuclear Fusion
Stichting Wageningen Research	Netherlands	Bioenergy
TNO	Netherlands	
RISE	Sweden	Energy Efficiency in Industry
RSE	Italy	
ITI	Greece	

It is clear from the analysis that certain organizations dominate across a wide range of subsectors. Despite a total of 548 identified RO's in the dataset, Fraunhofer (Germany), CEA (France), SINTEF (Norway), CNRS (France) and Tecnalia (Spain) are consistently among the top 5 RO's across at least six of the fifteen energy subsectors. The biggest RO has attracted in the vicinity of €100 million euros in Horizon 2020-funding over the course of the four years examined. Being a Research Organization can be big business.

3.3. Varying impact of ROs across sectors

The energy research projects in the database vary in both size, scope and aim. This is in part due to a variety in the amount of Horizon 2020-supported projects, as there has simply been initiated many more projects in certain sectors. It is our conclusion based on our research so far that the properties of projects in a given subsector to a large part can be derived of properties of the sector itself - in terms of technology readiness levels (TRL), needs for large scale investments etc. [11]

Research Organizations have different roles across the varied research landscapes, but their impact is recognizable in all cases. For classic RTO's with a background in applied research an increased EU-focus on collaboration with industrial partners and of greater diffusion of new technology corresponds with their bread-and-butter competencies. While the biggest RO's obtain a smaller share of the total funding in fields with high TRL's, as the number of stakeholder in the field is higher, they attract very significant funding in sectors like bioenergy and energy storage. During the timeframe examined Fraunhofer alone for example participated in 26 bioenergy projects and 24 projects related to energy storage. Several of these projects include integrating activities, and there is a clearly distinguishable trend in the database that projects funded as integrating activities attracts Research Organizations as participants.

In the fields of nuclear fission and nuclear fusion, where demands for organizational capacity in order to conduct significant research is much higher, a small number of RO's also dominate the European projects. Two RO's (SCK-CEN, CEA) each take part in more than half of all initiated projects during the timeframe analyzed[12].

4. Conclusions

Using publicly available quantitative data in the CORDIS-database it has been possible to show that Research Organizations are very important actors in the European science, technology and innovation landscape. RO's are among the main recipients of funding for projects through the Horizon 2020-programme where the funding amounts to a total of nearly €80 billion. Considering the means with which they are provided, and in order to generally improve invention, innovation and

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[11] The Horizon-programme also supports innovation, and the number of projects includes support for SMEs and commercialization of new technology. This is easier in fields with high technology-readiness levels compared to e.g. fusion energy.

[12] The nuclear sectors are otherwise slightly atypical, as many of the leading research organisations with a primary focus on applied research do not participate in nuclear projects at all. Of the 20 RTO's presented in Zacharewicz et al. (2017) only Finnish VTT has taken part in nuclear research projects during the time period.

diffusion of new technology in Europe, it is important to better understand the role of RO's at the European level.

With a database of 1 734 Energy Projects across 15 different energy research subsectors and containing a total of 548 RO's some trends can be distinguished about the role of RO's regarding energy research. First, some European Research Organizations have become very strong and influential across the board, at least in terms of attracting project funding. Second, there are major differences in RO's roles across subsectors which can perhaps be explained by varying inherent properties of the subsectors. Third, we have identified major differences across EU member states suggesting variance in RO's roles in national innovation systems. Fourth, a small number of RO's are involved in an especially large share of projects in subsectors where investments in large-scale research infrastructures (Big Science) are dominating, while a group of RO's have formed networks along several EU-supported integrating activities. This suggests that if the innovation policy of Europe consistently promotes *more* transnational cooperation and Big Science, Research Organizations will have an even more central role to the future innovation paradigm of the European Union.

A number of elements ought to be examined in more detail in future studies. First, academic research on Research Organizations have primarily focused on the impact on *diffusion*. If RO's take up an increasing share of research funds, the impact of RO's on *invention* and *innovation* needs to be understood better. Second, most studies have focused on the role of RO's as a driver of national or regional innovation and development, yet the European perspective seems promising to explore. Third, attention can be put on how increased international participation shape and possibly transform the RO's themselves. Fourth, and of major interest for policy planners, the observed variance in national innovation systems in the roles and impacts of ROs call for much further analysis. Fifth, and finally, efforts to understand how the changing innovation landscapes of the EU specifically affects energy research and the transition to sustainable energy would be informative in order to achieve the energy production and technology transition in an effective and positive manner.

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Energy Intensity, Energy Consumption and Changes in Energy Intensity in the EU-28 Countries in 1995-2014

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Abstract

This paper has a focus on (1) energy consumption and energy intensity in the EU-28 countries, in years 1995, 2000, 2008 2013 and 2014, (2) changes in energy intensity in the EU-28 countries, in years 1995-2000, 2005-2010, 2010-2014, (3) total changes in energy intensity in the EU-28 countries, in years 1995-2014, (4) final energy consumption per capita (all fuels kWh/cap) in the EU-28 countries, in years 1995, 2000, 2005, 2010, 2013 and 2014, (5) changes in final energy consumption per capita (all fuels kWh/cap) in the EU-28 countries, years 1995-2014, (6) total changes in final energy consumption per capita (all fuels kWh/cap) in the EU-28 countries, (7) primary energy intensity (toe/Meuros) in the EU-28 countries in years 1995, 2000, 2005, 2010, 2013 and 2014, (8) changes in primary energy intensity (toe/Meuros) in the EU-28 countries, in years 1995-2000, 2000-2005, 2005-2010, 2010-2014 and (9) total changes in primary energy intensity (toe/Meuros) in the EU-28 countries. The study reports various policy relevant results for the European Union and for the EU agencies.

The study confirms that the overall primary energy intensity of all EU member countries evolved towards the desired direction, but there are quite big differences among EU Member States in national energy efficiency efforts. The data of the study is collected from Eurostat databases.

1. Energy intensity in the EU-28 countries

The data of the study is collected from Eurostat databases.

In Fig. 3.1 we have reported energy intensity development in the EU-28 Countries, Years 1995, 2000, 2005, 2010, 2013 and 2014. The statistical data is from the Eurostat. We can observe big energy intensities in Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania and Slovakia. Low energy intensity can be observed in Denmark, Ireland, Italy, Luxembourg, Austria, Sweden and United Kingdom.

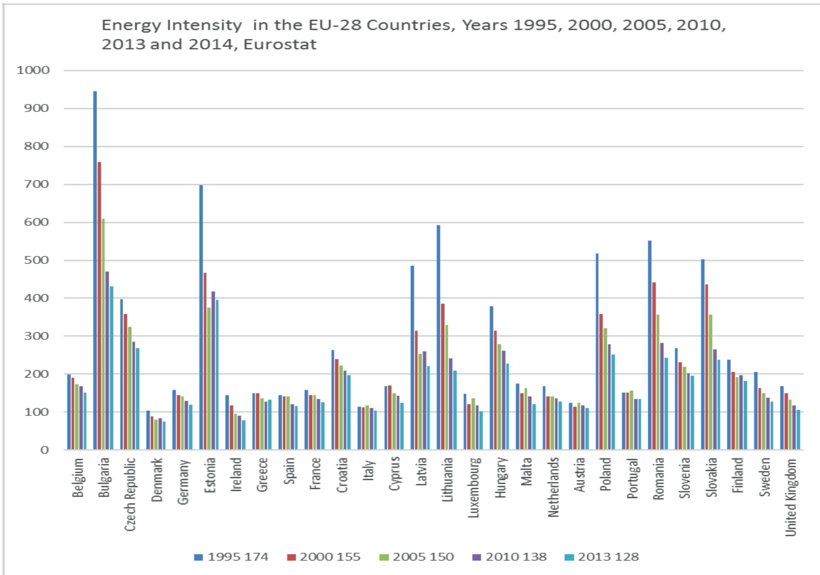

Figure 1.1. Energy intensity in the EU-28 Countries, Years 1995, 2000, 2005, 2010, 2013 and 2014, Eurostat.

Fig. 1.2 reports changes in energy intensity in the EU-28 countries. This figure reveals that in most EU-28 countries energy intensity has gone down in the period of 1995-2014. Especially Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania and Slovakia have been very successful in this special field of energy policy. In these countries energy policy transformation has been considerable and radical changes have happened. Some countries, like Estonia, Greece, Italy, Latvia, Luxembourg, Malta, Austria, Portugal and Finland have had some minor problems to decrease energy intensity.

After all, this general trend has been positive in the EU in this energy policy area. If we measure energy efficiency with this indicator, we can conclude that energy efficiency has improved in the EU-region.

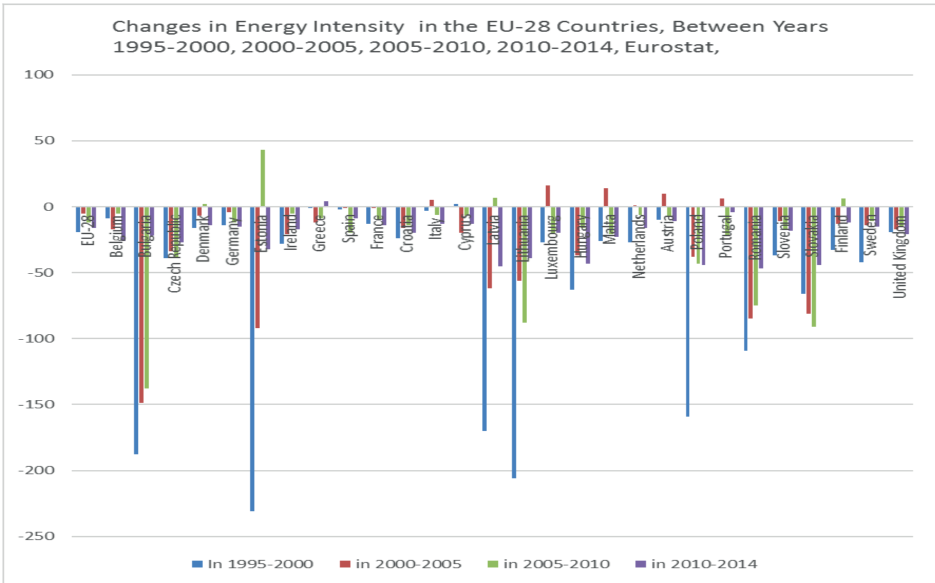

Figure 1.2. Changes in energy intensity in the EU-28 Countries, Years 1995-2000, 2005-2010, 2010-2014, Eurostat.

Fig. 1.3 informs about total changes in energy intensity in the EU-28 countries. Especially Bulgaria, Lithuania, Estonia, Latvia, Poland, Romania and Slovenia have decreased their energy intensity levels. All EU-28 countries have made some progress in this important energy policy field of energy economy

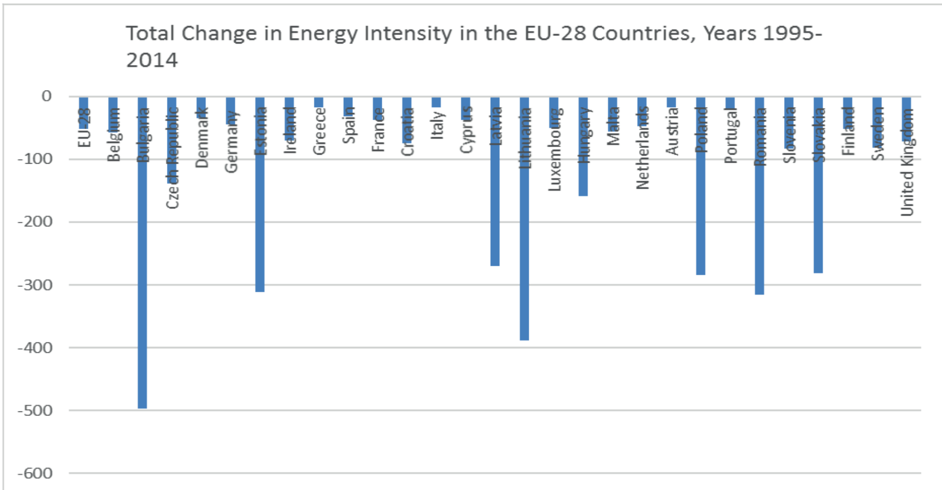

Figure 1.3. Total changes in energy intensity in the EU-28 Countries, Years 1995-2014, Eurostat.

Fig. 1.3 verifies a conclusion that the direction of energy saving and energy efficiency policies in the EU-28 have been right and some considerable results towards sustainability have been reached.

2. Energy consumption per capita in the EU-28

In Fig. 2.1 energy consumption per capita in the EU-28 countries have been reported in 1995, 2000, 2005, 2010 and 2014. This figure reveals that quite many EU-member states have been successful and some other EU-member states have not been so successful in decreasing energy consumption per capita. There are many countries, which have decreased energy consumption per capita. On very small number of EU-28 countries have not been very successful in this field of energy policy. Such countries are Estonia, Finland, Luxembourg and the Netherlands. Also among these countries some positive changes have happened in recent years. There are many countries where energy consumption has increased in 1995-2005, but later, in 2005-2014 it has decreased. We can conclude that there is a kind of turning point in European energy policy, if we measure energy policy progress by energy consumption per capita.

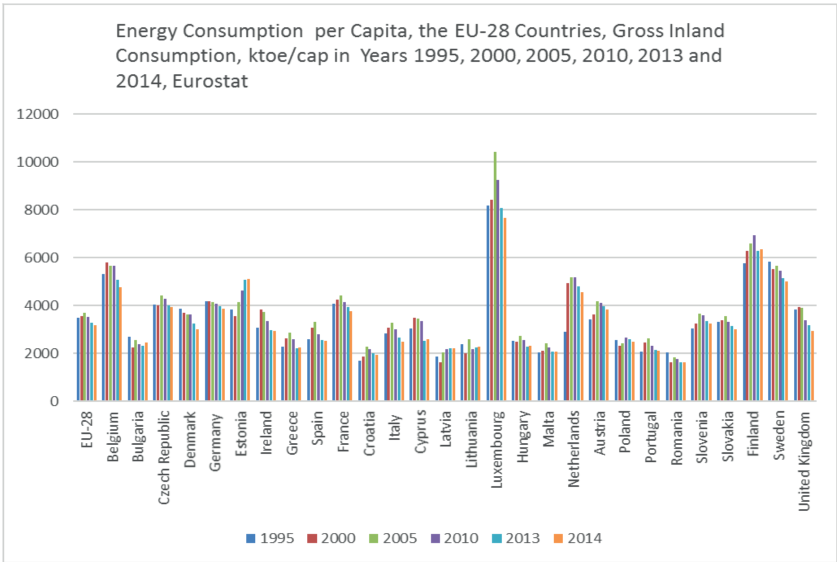

Figure 2.1. Final energy consumption per capita (all Fuels, kWh/cap) in the EU-28 Countries, Years 1995, 2000, 2005, 2010, 2013 and 2014, Eurostat.

Fig 2.2 reports changes in final energy consumption per capita (all Fuels, kWh/cap) in the EU-28 countries. This figure reveals that in most EU-28 countries energy consumption per capita increased in 1995-2010, but in 2010-2014 it started to decrease in considerable way in many EU-28 countries. We can explain this detectable change in final energy consumption per capita by the global financial crisis, but in any case, these changes in 2010-2014 are positive from the perspectives of global climate change policy and sustainable development.

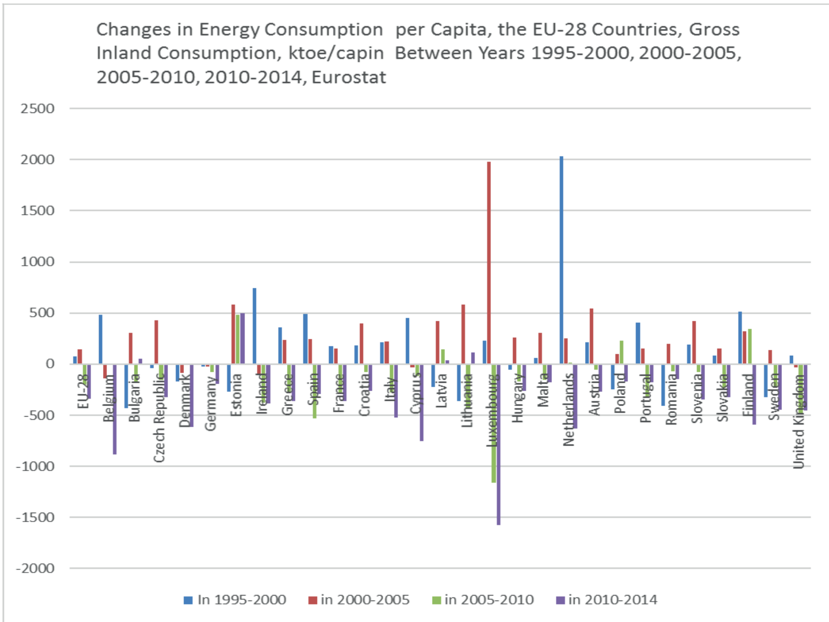

Figure 2.2. Changes in final energy consumption per capita (all Fuels, kWh/cap) in the EU-28 Countries, Years 1995-2000, 2005-2010, 2010-2014, Eurostat.

To get a better big picture, in Fig. 2.3, we have reported total changes in final energy consumption in the EU-28 countries. This figure reveals that many countries have decreased final energy consumption in capita in 1995-2014. Especially Czech Republic, Denmark, Luxembourg and Sweden have very successful countries in this energy policy field. Most EU-28 countries show decreases in this key variable of energy policy.

Biggest problems to decrease energy consumption per capita in in this period 1995-2014 have had the Luxembourg, Estonia, Finland, Austria and Latvia.

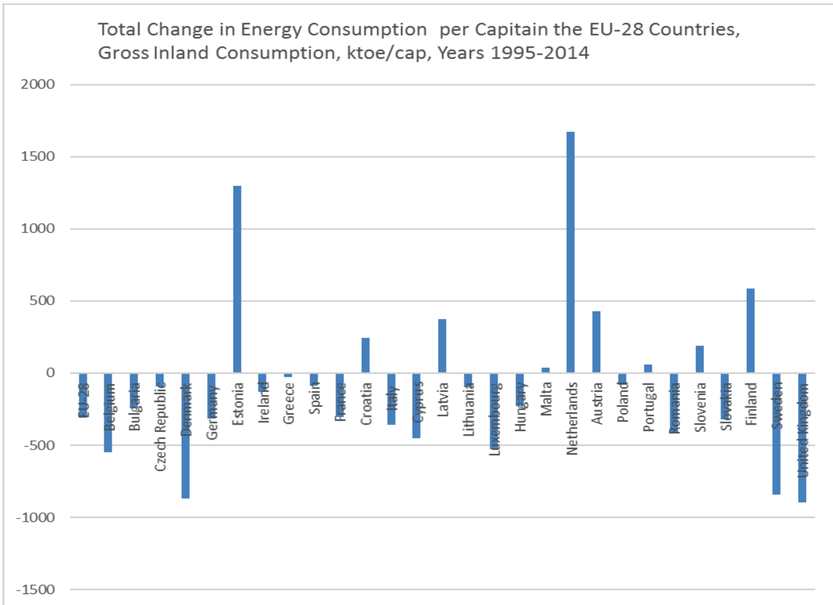

Figure 2.3. Total changes in final energy consumption per capita (all Fuels, kWh/cap) in the EU-28 Countries, Years 1995-2014, Eurostat.

3. Primary energy intensity in the EU-28 countries

In Fig. 3.1 we are reporting statistical figures of primary energy intensity in the EU-28 region. The time period of statistical analysis is 1995-2014. The general trend in the EU-28 countries has been that the primary energy intensity has fallen in most EU member states.

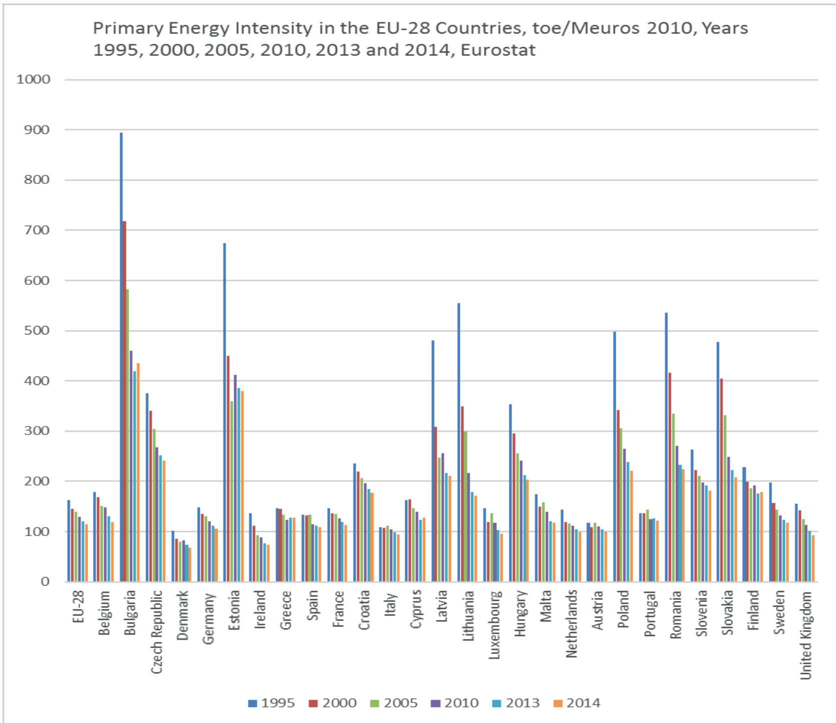

Figure 3.1. Primary energy intensity (toe/Meuros) in the EU-28 Countries, Years 1995, 2000, 2005, 2010, 2013 and 2014, Eurostat.

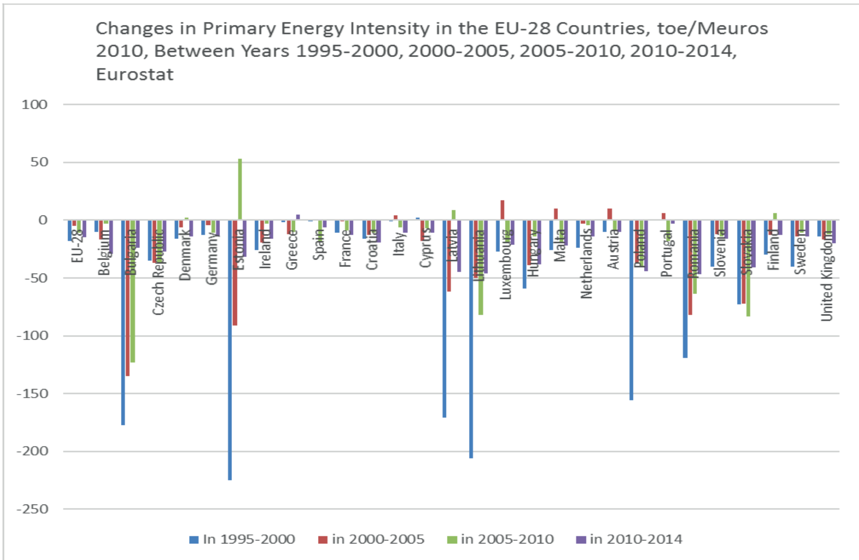

Figure 3.2. Changes in primary energy intensity (toe/Meuros) in the EU-28 countries, years 1995-2000, 2005-2010, 2010-2014, Eurostat.

In Fig. 3.2 we report changes in primary energy intensity in the EU-28 Countries, (toe/Meuros 2010), in 1995-2000, 2000-2005, 2005-2010 and 2010-2014. Figure 3.8 verifies conclusion that in recent years, primary energy intensity has fallen in most EU member states.

In Fig. 3.3, we have reported total changes in primary energy intensity in the EU-28 countries. This figure reveals that all EU-28 countries have decreased primary energy intensity in capita in 1995-2014. Especially Bulgaria, Estonia, Latvia, Lithuania, Hungary, Poland, Romania and Slovakia have been very successful countries in this energy policy field. Biggest problems to decrease primary energy intensity in this period 1995-2014 have had Mediterranean countries like Italy, Spain, Greece and Portugal. This is understandable because in these countries the level of energy intensity has already reached a low level.

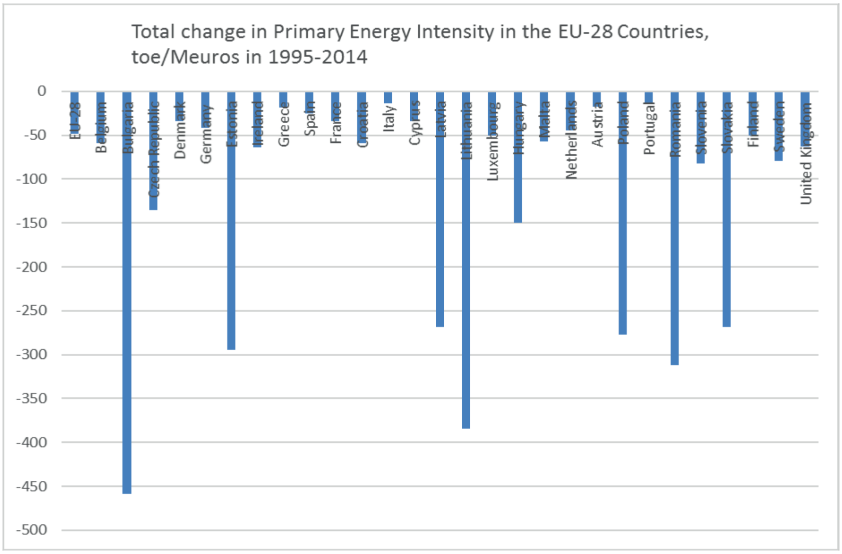

Figure 3.3. Total changes in primary energy intensity (toe/Meuros) in the EU-28 countries, years 1995-2014, Eurostat.

To sum up key results, Fig. 3.3 confirms that the overall primary energy intensity of all EU member countries evolved towards the desired direction.

4. Summary

This empirical benchmarking study confirms that the overall primary energy intensity of all EU member countries evolved towards the desired direction in 1995-2014, but there are quite big differences among EU Member States in national energy efficiency efforts.

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Decomposition of Total Primary Energy Supply: Energy Efficiency Trends in the EU-28 Member States in 1990-2013

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Abstract

One of the major policy targets of improving energy efficiency is to reduce energy use without a need to limit the activities where energy is used in the society. Nowadays energy efficiency is taken as a policy target as such but from the era of oil crises in the 1970s energy saving was commonly used instead up to the 1990s (cf. Kasanen 1990). Energy efficiency can be improved in the energy consumption side (final energy consumption) and in the energy production side (transforming primary energy into energy carriers). It is worth noting here, that the EU energy efficiency targets is not related to energy efficiency per se, but energy consumption in relation to projected future consumption. The decomposition analysis gives an insight to what extent these policy targets have been reached, and also an insight to the role of classical Jevons paradox (cf. Jevons 1866, Greening et al. 2000, Vehmas et al. 2003, Missemer 2012). Total primary energy supply (ΔTPES) will be decomposed into the relative contributions of the drivers. Data used in this decomposition analysis is taken from the International Energy Agency online database (IEA 2015). Similar decomposition analyses were performed by Kaivo-oja and Luukkanen (2004) and Vehmas (2009) in the case of the European Union.

This data includes total energy primary energy supply (TPES), final energy consumption (FEC), gross domestic product in real prices (in 2005 USD, adjusted y exchange rates), and number of population. This study elaborates long run energy efficiency trends in the EU-28 member states., The study reports the following results: (1) Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States and EU-15 and EU-28 aggregates in 1990-2005, (2) Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States and EU-15 and EU-28 aggregates in 2000-2005, (3) Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States and EU-15 and EU-28 aggregates in 2005-2010 and (4) Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States and EU-15 and EU-28 aggregates in 2010-2013.

In the sense how changes in energy efficiency related to indicators TPES/FEC and FEC/GDP have contributed to change in total primary energy supply (ΔTPES), the performance of EU Member States as well as the performance of the EU as a whole has been very different during the four different time periods, 1990-2000, 2000-2005, 2005-2010 and 2010-2013. The study provides a comprehensive empirical analysis about energy efficiency policy of the EU-28 countries in 1990-2013.

1. Introduction

Nowadays energy efficiency is taken as a policy target as such but from the era of oil crises in the 1970s energy saving was commonly used instead up to the 1990s (cf. Kasanen 1990). Energy efficiency can be improved in the energy consumption side (final energy consumption) and in the energy production side (transforming primary energy into energy carriers). It is worth noting here, that the EU energy efficiency targets is not related to energy efficiency per se, but energy consumption in relation to projected future consumption.

The decomposition analysis gives an insight to what extent these policy targets have been reached, and also an insight to the role of classical Jevons paradox (cf. Jevons 1866, Greening et al. 2000, Vehmas et al. 2003, Missemer 2012).

Total primary energy supply (ΔTPES) will be decomposed into the relative contributions of the drivers. Data used in this decomposition analysis is taken from the International Energy Agency online database (IEA 2015). This data includes total energy primary energy supply (TPES), final energy consumption (FEC), gross domestic product in real prices (in 2005 USD, adjusted y exchange rates), and number of population. This study elaborates long run energy efficiency trends in the EU-28 member states.

The results are based on an analysis of incremental (annual) changes, and they are always presented as percentage of a selected base year value of the decomposed indicator, i.e. total primary energy supply (TPES). Tables 1-4 show results from analyses carried out for the years 1990-2013, divided into four time periods: 1990-2000 (Table 1), 2000-2005 (Table 2), 2005-2010 (Table 3) and 2010-2013 (Table 4).

The main results are the relative contributions of the energy efficiency related drivers TPES/FEC and FEC/GDP, i.e. GDP/POP and POP, to the change of total primary energy supply (ΔTPES). The incremental effects are summed up for each time period and presented as percentage from the absolute TPES value of the first year of each time period.

2. Decomposition of total primary energy supply (TPES)

In Tables 1-4, for the effects of energy efficiency related drivers (TPES/FEC and FEC/GDP), basic statistical info (median, average, standard deviation and minimum and maximum values) on the annual effects during each of the selected time periods (as percentage of the previous year's TPES value) are presented as well.

In Tables 2-5, the most decreasing and the most increasing values for the effects of TPES/FEC and FEC/GDP have been marked with different shades of green (decreasing effect) and red (increasing effect). The scales of the shades are based on the following decrease/increase categories:

In the sense how changes in energy efficiency related indicators TPES/FEC and FEC/GDP have contributed to change in total primary energy supply (ΔTPES), the performance of EU Member States as well as the performance of the EU as a whole has been very different during the four different time periods, 1990-2000, 2000-2005, 2005-2010 and 2010.2013.

-20.00% or more	bright green
-19.99%…-10.00%	green
-9.99%...-2.50%	light green
-2.49% – 2.49%	white
2.50%…9.99%	light red
10.00%…19.99%	red
20.00% or more	bright red

In section 2 we shall report the main results of total primary energy supply (ΔTPES) decomposition analysis for EU Member States and EU15 and EU-28 aggregates. Time periodic results are provided (years 1990-2000, 2000-2005, 2005-2010, 2010-2013).

2.1. Results of total primary energy supply (ΔTPES) decomposition analysis for EU Member States and EU15 and EU-28 aggregates

In Table 1 the results of total primary energy supply (ΔTPES) decomposition analysis for EU Member States and EU15 and EU-28 aggregates, 1990-2000 are reported.

Table 1. Results of total primary energy supply (ΔTPES) decomposition analysis for EU Member States and EU15 and EU-28 aggregates, 1990-2000. Cumulative effects are sums of incremental (annual) effects.

EU-28 Member State	ΔTPES 1990-2000, % of 1990 TPES	Cumulative TPES/FEC effect, % of 1990 TPES	Statistical info on incremental TPES/FEC effects, % of previous year's TPES					Cumulative FEC/GDP effect, % of 1990 TPES	Statistical info on incremental FEC/GDP effects, % of previous year's TPES					Cumulative GDP/POP effect, % of 1990 TPES	Cumulative POP effect, % of 1990 TPES
			Md	Av.	Stdev	Min	Max		Md	Av.	Stdev	Min	Max		
Austria	6.6	-1.9	-0.4	-0.4	1.3	-2.3	2.3	-4.1	-2.1	-0.8	3.7	-5.0	6.1	10.6	2.0
Belgium	9.7	-3.1	-0.5	-0.7	1.1	-3.1	1.1	1.2	-0.4	0.4	3.3	-4.7	5.6	10.2	1.4
Bulgaria	-12.9	5.4	2.2	1.8	3.6	-4.6	6.4	-15.2	-5.0	-4.7	6.7	-19.5	2.6	-1.2	-1.9
Croatia	-6.0	-2.0	-0.8	-0.5	3.1	-5.2	4.6	2.6	-2.2	1.0	7.8	-8.3	18.3	-3.5	-3.0
Cyprus	19.8	-1.4	2.3	-0.2	8.2	-15.2	10.5	2.4	-1.3	0.9	5.0	-3.5	13.2	10.4	8.4
Czech	-5.8	1.3	0.8	0.5	2.2	-3.7	3.1	-7.9	-2.6	-2.8	2.0	-6.9	-0.3	1.1	-0.3
Denmark	2.5	-0.3	-0.8	0.1	4.4	-5.0	9.0	-7.4	-3.1	-1.8	3.8	-5.8	4.8	8.7	1.5
Estonia	-14.1	1.9	-0.4	0.7	4.4	-6.1	9.7	-12.9	-9.9	-7.3	9.1	-17.3	9.9	-0.7	-2.4
Finland	7.3	1.6	0.1	0.4	3.6	-5.9	5.8	-8.0	-1.8	-1.3	3.9	-7.7	5.4	11.7	2.1
France	8.1	-1.0	-0.2	-0.1	2.1	-2.6	3.7	-5.6	-1.2	-0.7	3.0	-3.4	6.1	11.5	3.1
Germany	-1.6	-0.1	-0.3	0.0	0.8	-1.2	1.5	-8.5	-3.4	-2.3	2.8	-6.1	3.0	5.8	1.3
Greece	8.1	-0.2	0.2	-0.1	2.2	-4.2	2.5	-0.2	-0.5	0.0	2.3	-4.1	4.4	6.6	1.8
Hungary	-5.8	1.8	0.7	0.4	2.5	-3.4	4.0	-8.1	-2.7	-2.1	4.5	-9.4	6.3	1.2	-0.6
Ireland	12.9	-1.2	0.0	-0.2	1.5	-3.6	1.8	-12.4	-3.1	-3.4	2.6	-8.4	0.1	23.5	3.1
Italy	6.4	1.8	0.1	0.5	1.6	-1.1	4.2	-2.0	0.2	-0.5	1.8	-4.0	1.4	6.5	0.2
Latvia	-21.4	-1.7	-0.5	-0.5	1.3	-2.7	1.6	-5.2	-8.0	-3.8	10.0	-11.1	18.9	-11.3	-3.2
Lithuania	-27.7	2.9	2.3	0.6	7.0	-10.4	8.5	-16.0	-6.9	-4.7	9.3	-20.3	12.0	-13.2	-1.5
Luxembourg	-0.4	-5.2	-1.2	-1.7	1.4	-3.9	-0.1	-10.2	-2.8	-3.3	3.2	-9.1	1.7	10.5	4.6
Malta	-0.4	-5.7	-4.5	-1.5	11.8	-18.5	18.6	-11.0	-4.5	-3.2	10.2	-20.1	11.2	13.7	2.6
Netherlands	5.2	-1.7	-0.4	-0.4	1.2	-2.0	1.3	-8.5	-1.7	-1.7	3.6	-6.9	5.1	12.3	3.1
Poland	-4.2	-2.6	0.0	-0.9	1.9	-5.0	0.7	-11.9	-6.0	-4.2	6.2	-11.6	7.7	10.1	0.2
Portugal	20.6	0.5	0.0	0.2	3.7	-4.8	7.2	4.5	1.1	0.9	2.1	-3.4	4.0	14.0	1.7
Romania	-15.5	1.7	-0.2	0.5	6.0	-9.6	11.0	-11.3	-4.8	-4.0	6.3	-11.5	8.1	-4.8	-1.0
Slovakia	-6.5	4.7	0.9	1.3	3.6	-4.4	8.7	-13.2	-2.9	-4.0	4.3	-12.4	0.3	1.3	0.6
Slovenia	5.2	-5.0	-1.4	-1.2	2.6	-5.9	3.1	1.4	-1.1	0.6	5.2	-4.9	9.7	8.9	-0.2
Spain	15.7	-2.1	-0.3	-0.4	1.3	-2.1	2.0	3.4	1.5	0.7	1.8	-2.0	3.0	12.7	1.7
Sweden	0.7	-8.0	-0.4	-0.8	4.0	-10.1	4.2	-11.7	-1.6	-1.2	4.1	-5.9	6.8	17.1	3.3
UK	3.1	-0.3	0.0	-0.1	0.8	-1.5	1.1	-6.1	-2.3	-1.5	3.2	-5.0	5.4	8.4	1.1
EU-15	*4.3*	*-0.5*	*-0.1*	*-0.1*	*0.4*	*-0.5*	*0.6*	*-5.3*	*-1.6*	*-1.2*	*1.7*	*-3.0*	*1.8*	*8.7*	*1.5*
EU-28	*1.2*	*-0.5*	*-0.1*	*-0.1*	*0.4*	*-0.6*	*0.8*	*-7.3*	*-2.6*	*-1.8*	*1.8*	*-3.3*	*2.0*	*8.1*	*0.8*

In Table 2 the results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States, 2000-2005 are reported.

Table 2. Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States, 2000-2005. Cumulative effects are sums of incremental (annual) effects.

EU-28 Member State	DTPES 2000-2005, % of 2000 TPES	Cumulative TPES/FEC effect, % of 2000 TPES	Statistical info on incremental TPES/FEC effects, % of previous year's TPES					Cumulative FEC/GDP effect, % of 2000 TPES	Statistical info on incremental FEC/GDP effects, % of previous year's TPES					Cumulative GDP/POP effect, % of 2000 TPES	Cumulative POP effect, % of 2000 TPES
			Md	Av.	Stdev	Min	Max		Md	Av.	Stdev	Min	Max		
Austria	8.5	0.3	0.2	0.1	0.4	-0.4	0.5	3.8	0.7	1.6	2.9	-1.0	4.8	3.0	1.4
Belgium	0.2	0.0	0.9	0.0	1.6	-2.3	1.4	-4.3	-2.1	-1.7	3.4	-6.4	2.2	3.3	1.1
Bulgaria	3.1	-0.7	0.4	-0.3	3.6	-5.1	4.1	-7.8	-3.7	-3.4	4.3	-8.5	2.3	14.0	-2.5
Croatia	6.6	-1.2	-0.7	-0.4	2.1	-3.6	1.5	-3.2	-2.7	-1.3	2.2	-3.0	2.0	10.9	0.1
Cyprus	1.3	-2.2	-0.6	-1.1	5.0	-8.9	4.7	-2.1	-1.5	-1.2	2.3	-3.2	2.1	3.6	1.9
Czech	3.3	0.7	0.0	0.4	1.8	-1.0	3.5	-4.4	-1.5	-2.4	3.1	-6.9	1.1	7.1	-0.1
Denmark	0.5	-1.3	0.4	-0.6	3.2	-4.3	3.5	-0.8	-1.5	-0.4	2.0	-2.0	1.9	2.0	0.6
Estonia	3.4	-2.3	-2.8	-1.3	4.1	-4.6	5.7	-6.2	-2.6	-3.5	4.7	-9.0	3.0	13.0	-1.0
Finland	3.7	1.5	1.3	0.6	3.2	-4.5	4.0	-6.1	-1.1	-1.8	2.7	-5.8	1.3	7.4	0.9
France	5.3	2.9	0.5	0.8	1.1	-0.2	2.6	-3.6	-1.8	-1.0	2.2	-3.5	1.5	3.3	2.6
Germany	0.1	0.2	0.3	0.1	1.2	-1.5	1.2	-1.3	-1.5	-0.6	1.5	-1.8	1.7	1.1	0.1
Greece	3.6	-0.3	-0.1	-0.2	1.9	-2.5	2.8	-2.3	-1.0	-1.4	2.6	-5.8	1.1	5.7	0.5
Hungary	4.8	-2.5	-1.2	-1.0	0.3	-1.2	-0.5	-2.8	-0.7	-1.1	2.8	-4.4	2.6	10.6	-0.6
Ireland	1.9	-2.5	-0.6	-1.4	3.2	-6.0	2.1	-4.0	-2.3	-2.3	2.6	-6.0	1.1	5.1	3.2
Italy	2.9	-0.2	0.4	-0.1	1.1	-2.0	0.6	1.1	0.3	0.5	1.7	-0.7	3.4	1.0	0.9
Latvia	10.2	-2.4	-1.0	-0.8	1.5	-2.3	1.2	-11.9	-4.9	-3.8	3.3	-7.2	1.3	27.9	-3.5
Lithuania	16.8	0.4	1.5	0.7	7.7	-10.2	11.1	-15.8	-2.8	-3.7	2.0	-7.0	-2.0	36.9	-4.6
Luxembourg	12.9	2.0	0.6	0.9	2.1	-1.3	4.3	3.5	2.3	1.6	4.5	-3.6	6.3	4.2	3.3
Malta	9.4	10.6	5.7	6.1	13.0	-9.0	19.6	-3.0	-1.7	-1.3	15.2	-16.3	18.0	0.0	1.8
Netherlands	3.3	0.7	0.4	0.3	0.8	-0.5	1.4	-0.4	-0.5	-0.1	2.1	-2.6	3.2	1.7	1.2
Poland	1.2	-1.2	-0.1	-0.8	1.5	-3.4	0.5	-2.4	-1.4	-1.5	1.1	-3.1	-0.1	4.8	-0.1
Portugal	3.2	0.8	0.7	0.4	2.0	-2.9	2.2	0.5	0.3	0.2	1.2	-1.3	1.6	1.0	0.9
Romania	2.7	-1.1	0.0	-0.4	3.5	-5.1	4.4	-8.7	-4.3	-4.0	1.9	-5.8	-1.5	14.8	-2.2
Slovakia	3.0	1.7	-0.2	0.7	2.1	-1.1	4.1	-11.2	-3.7	-4.4	3.7	-9.9	0.1	12.5	-0.1
Slovenia	6.3	1.2	0.7	0.5	1.9	-2.6	2.2	-3.6	-1.3	-1.5	2.2	-4.6	0.9	8.5	0.2
Spain	7.2	-1.1	-0.6	-0.5	1.7	-2.1	1.5	0.5	0.3	0.2	1.5	-1.4	2.4	4.0	3.8
Sweden	7.7	9.9	1.3	2.1	3.4	-1.3	6.8	-14.9	-3.4	-3.0	1.5	-4.8	-0.9	11.0	1.8
UK	-0.1	0.6	0.3	0.3	0.9	-0.9	1.5	-6.8	-3.0	-3.2	1.0	-4.6	-2.0	5.1	1.1
EU-15	*2.4*	*0.5*	*0.2*	*0.2*	*0.4*	*-0.5*	*0.6*	*-2.2*	*-1.5*	*-0.9*	*1.4*	*-2.2*	*1.0*	*2.9*	*1.3*
EU-28	*2.5*	*0.2*	*0.0*	*0.1*	*0.4*	*-0.4*	*0.7*	*-2.1*	*-1.4*	*-0.9*	*1.3*	*-2.3*	*1.0*	*3.6*	*0.8*

In Table 3 the results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States, 2005-2010 are reported.

Table 3. Results of total primary energy supply (ΔTPES) decomposition analysis for EU-28 Member States, 2005-2010. Cumulative effects are sums of incremental (annual) effects.

EU-28 Member State	DTPES 2005-2010, % of 2005 TPES	Cumulative TPES/FEC effect, % of 2005 TPES	Statistical info on incremental TPES/FEC effects, % of previous year's TPES					Cumulative FEC/GDP effect, % of 2005 TPES	Statistical info on incremental FEC/GDP effects, % of previous year's TPES					Cumulative GDP/POP effect, % of 2005 TPES	Cumulative POP effect, % of 2005 TPES
			Md	Av.	Stdev	Min	Max		Md	Av.	Stdev	Min	Max		
Austria	0.5	-0.3	0.4	-0.1	1.6	-2.7	1.6	-2.1	-0.6	-0.9	3.5	-5.2	3.3	2.2	0.7
Belgium	2.1	-0.4	0.8	-0.2	2.5	-4.3	2.3	-1.0	-3.3	-0.3	5.7	-5.5	6.3	1.4	2.1
Bulgaria	-4.4	0.7	-0.7	0.4	1.8	-1.1	3.3	-11.3	-5.8	-5.2	4.1	-10.2	0.2	8.1	-1.9
Croatia	-1.7	-1.1	-1.0	-0.5	2.8	-4.3	3.2	-1.7	-0.4	-0.8	2.8	-4.0	2.4	1.3	-0.2
Cyprus	3.1	0.6	1.9	0.5	2.5	-3.0	2.8	-1.6	-1.4	-1.0	1.6	-2.8	1.1	0.1	4.0
Czech	-0.5	1.4	1.5	0.8	2.7	-2.6	3.5	-6.6	-2.3	-3.4	3.6	-8.4	-0.1	3.6	1.1
Denmark	1.2	0.8	-0.2	0.5	3.3	-2.7	6.1	0.2	-0.5	0.1	2.4	-2.7	3.9	-0.8	0.9
Estonia	2.4	3.3	0.5	2.3	6.0	-2.8	11.3	-0.4	1.4	-0.3	5.6	-9.5	4.5	0.2	-0.7
Finland	4.2	1.4	-0.3	0.5	2.2	-1.6	3.9	-0.2	0.9	0.1	4.6	-4.8	6.8	1.6	1.4
France	-2.5	0.5	0.2	0.1	0.3	-0.4	0.4	-5.8	-1.6	-1.6	2.1	-3.9	1.1	0.7	2.0
Germany	-1.3	-0.9	-1.1	-0.5	1.3	-1.8	1.0	-3.0	0.5	-1.3	4.7	-9.3	2.3	3.0	-0.4
Greece	-2.8	-0.7	-0.6	-0.5	2.4	-2.9	3.5	-1.7	-1.5	-1.1	1.8	-2.9	1.6	-0.5	0.2
Hungary	-3.4	1.3	0.5	0.5	1.9	-2.1	2.7	-4.5	-1.6	-1.8	3.5	-5.4	2.6	0.2	-0.4
Ireland	-0.3	1.7	1.0	1.0	4.7	-3.7	6.0	-2.3	-1.2	-1.4	4.6	-8.1	4.6	-2.8	3.1
Italy	-3.0	-0.5	-0.1	-0.2	1.0	-1.3	1.2	-2.0	0.0	-1.0	2.5	-3.9	1.8	-1.6	1.1
Latvia	-0.3	-0.5	-0.3	-0.1	1.0	-1.4	1.0	1.9	-0.8	0.7	9.2	-7.6	15.6	2.2	-3.9
Lithuania	-14.7	-14.9	-4.4	-4.4	11.4	-21.9	7.2	-3.3	0.1	-0.8	3.6	-6.2	3.1	8.5	-4.9
Luxembourg	-1.5	-0.1	-0.3	0.0	0.7	-0.8	1.1	-5.5	-1.8	-2.9	4.2	-8.6	1.3	1.2	3.0
Malta	-2.2	-10.2	-5.7	-6.3	12.3	-24.6	9.3	4.3	1.0	2.7	9.2	-7.7	16.4	2.2	1.5
Netherlands	3.1	-0.9	0.5	-0.4	3.3	-5.8	2.7	0.3	-1.1	0.2	5.6	-7.2	6.6	2.8	0.9
Poland	2.8	-1.3	-1.1	-0.8	1.2	-2.3	0.5	-3.4	-2.9	-2.1	3.8	-6.0	4.1	7.2	0.3
Portugal	-4.8	-1.7	-1.3	-0.8	2.5	-3.6	1.8	-4.4	-1.7	-2.1	2.7	-5.2	1.0	1.0	0.3
Romania	-3.9	0.3	0.4	0.2	2.3	-3.2	2.8	-10.4	-4.7	-4.9	3.7	-8.2	0.9	8.4	-2.2
Slovakia	-2.7	-1.5	0.1	-0.6	2.8	-5.4	1.7	-12.3	-3.0	-4.9	4.6	-10.7	0.6	10.8	0.4
Slovenia	-0.3	-0.1	-0.6	-0.1	1.3	-1.3	1.4	-4.2	-2.7	-1.7	4.8	-8.1	3.0	2.9	1.2
Spain	-4.3	-0.1	-0.9	-0.1	1.7	-1.5	2.6	-6.5	-3.7	-3.0	3.2	-6.8	1.4	-0.4	2.7
Sweden	-1.4	-2.2	-0.8	-0.4	3.2	-4.8	3.1	-7.4	-2.8	-1.4	3.4	-5.4	2.9	4.3	3.8
UK	-3.8	-0.7	-1.0	-0.3	1.3	-1.4	1.7	-4.3	-3.1	-2.1	3.4	-5.1	2.8	-0.3	1.5
EU-15	*-2.0*	*-0.5*	*-0.3*	*-0.2*	*0.5*	*-0.6*	*0.5*	*-3.3*	*-0.9*	*-1.4*	*2.8*	*-4.4*	*2.5*	*0.6*	*1.2*
EU-28	*-1.7*	*-0.5*	*-0.3*	*-0.2*	*0.5*	*-0.6*	*0.6*	*-3.3*	*-1.1*	*-1.4*	*2.7*	*-4.4*	*2.4*	*1.3*	*0.8*

In Table 4 the results of total primary energy supply (∆TPES) decomposition analysis for EU-28 Member States, 2010-2013 are reported.

Table 4. Results of total primary energy supply (∆PES) decomposition analysis for EU-28 Member States, 2010-2013. Cumulative effects are sums of incremental (annual) effects.

EU-28 Member State	DTPES 2005-2010, % of 2005 TPES	Cumulative TPES/FEC effect, % of 2005 TPES	Statistical info on incremental TPES/FEC effects, % of previous year's TPES					Cumulative FEC/GDP effect, % of 2005 TPES	Statistical info on incremental FEC/GDP effects, % of previous year's TPES					Cumulative GDP/POP effect, % of 2005 TPES	Cumulative POP effect, % of 2005 TPES
			Md	Av.	Stdev	Min	Max		Md	Av.	Stdev	Min	Max		
Austria	0.5	-0.3	0.4	-0.1	1.6	-2.7	1.6	-2.1	-0.6	-0.9	3.5	-5.2	3.3	2.2	0.7
Belgium	2.1	-0.4	0.8	-0.2	2.5	-4.3	2.3	-1.0	-3.3	-0.3	5.7	-5.5	6.3	1.4	2.1
Bulgaria	-4.4	0.7	-0.7	0.4	1.8	-1.1	3.3	-11.3	-5.8	-5.2	4.1	-10.2	0.2	8.1	-1.9
Croatia	-1.7	-1.1	-1.0	-0.5	2.8	-4.3	3.2	-1.7	-0.4	-0.8	2.8	-4.0	2.4	1.3	-0.2
Cyprus	3.1	0.6	1.9	0.5	2.5	-3.0	2.8	-1.6	-1.4	-1.0	1.6	-2.8	1.1	0.1	4.0
Czech	-0.5	1.4	1.5	0.8	2.7	-2.6	3.5	-6.6	-2.3	-3.4	3.6	-8.4	-0.1	3.6	1.1
Denmark	1.2	0.8	-0.2	0.5	3.3	-2.7	6.1	0.2	-0.5	0.1	2.4	-2.7	3.9	-0.8	0.9
Estonia	2.4	3.3	0.5	2.3	6.0	-2.8	11.3	-0.4	1.4	-0.3	5.6	-9.5	4.5	0.2	-0.7
Finland	4.2	1.4	-0.3	0.5	2.2	-1.6	3.9	-0.2	0.9	0.1	4.6	-4.8	6.8	1.6	1.4
France	-2.5	0.5	0.2	0.1	0.3	-0.4	0.4	-5.8	-1.6	-1.6	2.1	-3.9	1.1	0.7	2.0
Germany	-1.3	-0.9	-1.1	-0.5	1.3	-1.8	1.0	-3.0	0.5	-1.3	4.7	-9.3	2.3	3.0	-0.4
Greece	-2.8	-0.7	-0.6	-0.5	2.4	-2.9	3.5	-1.7	-1.5	-1.1	1.8	-2.9	1.6	-0.5	0.2
Hungary	-3.4	1.3	0.5	0.5	1.9	-2.1	2.7	-4.5	-1.6	-1.8	3.5	-5.4	2.6	0.2	-0.4
Ireland	-0.3	1.7	1.0	1.0	4.7	-3.7	6.0	-2.3	-1.2	-1.4	4.6	-8.1	4.6	-2.8	3.1
Italy	-3.0	-0.5	-0.1	-0.2	1.0	-1.3	1.2	-2.0	0.0	-1.0	2.5	-3.9	1.8	-1.6	1.1
Latvia	-0.3	-0.5	-0.3	-0.1	1.0	-1.4	1.0	1.9	-0.8	0.7	9.2	-7.6	15.6	2.2	-3.9
Lithuania	-14.7	-14.9	-4.4	-4.4	11.4	-21.9	7.2	-3.3	0.1	-0.8	3.6	-6.2	3.1	8.5	-4.9
Luxembourg	-1.5	-0.1	-0.3	0.0	0.7	-0.8	1.1	-5.5	-1.8	-2.9	4.2	-8.6	1.3	1.2	3.0
Malta	-2.2	-10.2	-5.7	-6.3	12.3	-24.6	9.3	4.3	1.0	2.7	9.2	-7.7	16.4	2.2	1.5
Netherlands	3.1	-0.9	0.5	-0.4	3.3	-5.8	2.7	0.3	-1.1	0.2	5.6	-7.2	6.6	2.8	0.9
Poland	2.8	-1.3	-1.1	-0.8	1.2	-2.3	0.5	-3.4	-2.9	-2.1	3.8	-6.0	4.1	7.2	0.3
Portugal	-4.8	-1.7	-1.3	-0.8	2.5	-3.6	1.8	-4.4	-1.7	-2.1	2.7	-5.2	1.0	1.0	0.3
Romania	-3.9	0.3	0.4	0.2	2.3	-3.2	2.8	-10.4	-4.7	-4.9	3.7	-8.2	0.9	8.4	-2.2
Slovakia	-2.7	-1.5	0.1	-0.6	2.8	-5.4	1.7	-12.3	-3.0	-4.9	4.6	-10.7	0.6	10.8	0.4
Slovenia	-0.3	-0.1	-0.6	-0.1	1.3	-1.3	1.4	-4.2	-2.7	-1.7	4.8	-8.1	3.0	2.9	1.2
Spain	-4.3	-0.1	-0.9	-0.1	1.7	-1.5	2.6	-6.5	-3.7	-3.0	3.2	-6.8	1.4	-0.4	2.7
Sweden	-1.4	-2.2	-0.8	-0.4	3.2	-4.8	3.1	-7.4	-2.8	-1.4	3.4	-5.4	2.9	4.3	3.8
UK	-3.8	-0.7	-1.0	-0.3	1.3	-1.4	1.7	-4.3	-3.1	-2.1	3.4	-5.1	2.8	-0.3	1.5
EU-15	*-2.0*	*-0.5*	*-0.3*	*-0.2*	*0.5*	*-0.6*	*0.5*	*-3.3*	*-0.9*	*-1.4*	*2.8*	*-4.4*	*2.5*	*0.6*	*1.2*
EU-28	*-1.7*	*-0.5*	*-0.3*	*-0.2*	*0.5*	*-0.6*	*0.6*	*-3.3*	*-1.1*	*-1.4*	*2.7*	*-4.4*	*2.4*	*1.3*	*0.8*

3. Summary

In this article we have elaborated total primary energy supply (∆TPES) decomposition analysis for EU-28 Member States for four time periods. These results are very policy relevant for European energy policy makers, because they provide useful perspective to European energy efficiency policy. These empirical analyses and associated results provide a comprehensive benchmarking of developments and progress towards more energy efficient European Union in years 1990-2013. The analysis was made for the period 1990-2013 using incremental (annual) changes for the first time, and the results were presented as incremental sums for four time periods, the first one was ten years (1990-2000), then two five-year periods (2000-2005, 2005-2010) and the most recent three-year period (2010-2013)

The indicators of energy efficiency used in this study are energy intensity of the economy (final energy consumption FEC divided by gross domestic product GDP in fixed USD 2005 prices) and efficiency of the energy transformation system, ratio of total primary energy supply TPES and final energy consumption FEC). The long-term trends of these indicators can be heavily generalized by saying that energy intensity has decreased significantly in most of the EU-28 Member States, but the trend of TPES/FEC ratio is not so clear and varies a lot between different Member States. Increasing use of electricity affects the TPES/FEC ratio very differently, depending on the used primary energy sources (fossil, nuclear, renewables) and modes of electricity production (CHP, condensing power).

Essential here is to underline, how primary energy is calculated in energy statistics. In some case, such as hydro, wind, and solar, produced electricity is calculated as such also in primary energy, in some other cases such as nuclear or geothermal, a thermal efficiency is assumed. This may make the use of aggregated energy indicators and their international comparison problematic, but not useless. Among many interesting findings, our study informs us that he EU Member States relying on nuclear power and fossil fuels may have a stronger increasing trend in the TPES/FEC ratio than Member States relying on energy sources.

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Impacts of Main Economic Sectors on Energy Efficiency in the Time Period 2015–2030 in China

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Abstract

This article presents q summary of Chinese sectoral energy intensity trends and a decomposition analysis of Chinese economic sectors at different levels of aggregation to get an understanding of the energy efficiency development and measure the energy efficiency improvement performance of the different sectors. The observed energy efficiency trends are used as parameters of the China-LINDA model to create a projection of possible development of energy use and emissions in China, and compared to a projection where aspired energy efficiency targets of the 13th five-year plan are reached. The analysis of the sectoral energy intensity developments and the structural decomposition analysis bring forth a number of sectors with low performance of energy efficiency improvements in relation to the average trend of development in the Chinese economy and possibly, have potential for greater energy savings through efficiency improvements.

1. Introduction

Chinese economy is growing fast and the rapidly expanding volume of economic activity drives the increasing energy use. This is illustrated in Figure 1. It is easy to observe that the energy intensity of GDP is decreasing, but it is difficult to clearly observe energy efficiency trends from simply looking at the final energy consumption and gross domestic product.

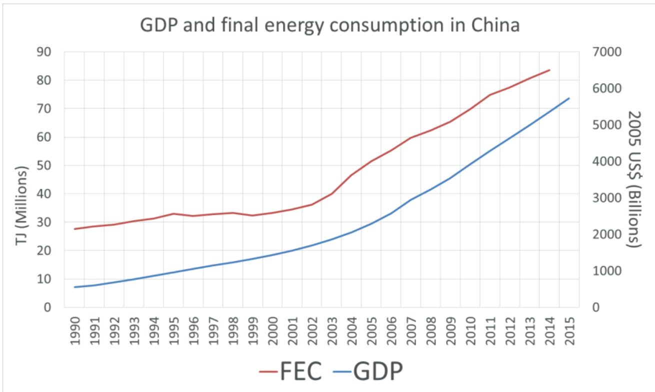

Figure 1. Gross domestic product and final energy consumption at national level in China. (World Bank: World Development Indicators [3]; International Energy Agency: Energy Balances [5]).

Concurrently, a structural shift is taking place in the Chinese economy, as the service sector activities increase in their relative volume as measured by GDP (see e.g. Sun

1998, Luukkanen et al. 2015). The service sector activities tend to be less energy-intensive as the industrial sector activities, so this structural shift, on the level of the whole economy, normally reduces energy consumption. The development of the sectoral value added is illustrated in Figure 2. To quantify the energy efficiency improvements and to analyse their impact on energy use, it is necessary to isolate the effect of the economic growth and the effect of the structural shift towards less energy-intensive activities from the effect of energy efficiency improvements. This can be accomplished with structural decomposition analysis. In this report we analyse the energy efficiency trends in China in two levels: the more aggregated level with a five-sector division, all industry subsectors treated as one single sector, and a more disaggregated level with 24 economic sectors. The aggregated level analysis provides an overview to the energy efficiency trends in China and an understanding of the phase of the structural shift towards service-oriented economy. The 24-sector structural decomposition analysis gives more detailed information on the energy intensity developments and efficiency potential especially on different industrial sectors.

2. Data of Chine energy intensity and decomposition study

The following structural decomposition analysis of Chinese economy uses data from National Bureau of Statistics of China and the World Input-Output Database. The sectoral final energy consumption data has been extracted from National Bureau of Statistics of China database (Chinese National Statistics, National Bureau of Statistics of China 2017). The sectoral value added data is sourced from the World Input-Output Database (World Bank 2017). The used databases do not have a fully matching sectoral division. Some economic subsectors have been combined in both databases to match the statistical items so that the structural decomposition analysis would be possible (see e.g. Timmer et al. 2015). The detailed data collection process is reported in the deliverable report.

Energy efficiency trends on the national level

Figure 2 shows the development of the sectoral value added in China. The growth of value added in the agricultural sector and the transport sector is slow compared to the growth of value added in the industrial and service sector. It is noteworthy that the service sector value added remains smaller than in the industrial sector. In China, the next ten years might bring about significant shift in the focus in economic activity to service sector, which likely will contribute to reducing energy consumption.

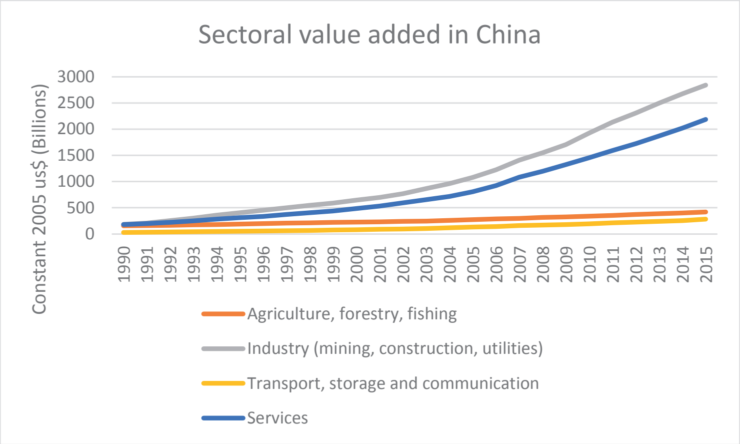

Figure 2. Sectoral value added in China 1990-2015. (World Bank: World Development Indicators; International Energy Agency: Energy Balances).

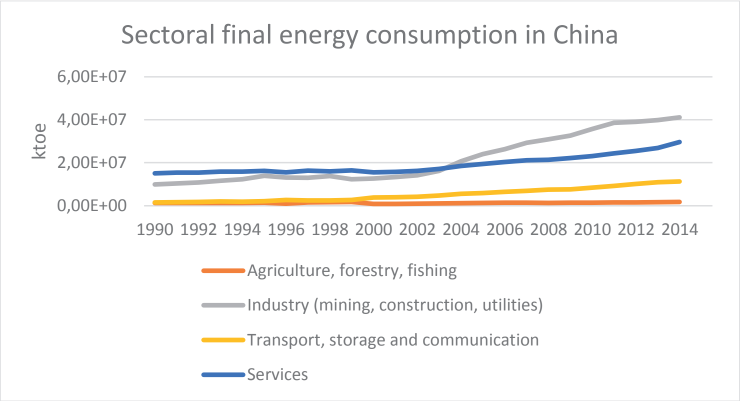

Figure 3. Sectoral final energy consumption in China (World Bank: World Development Indicators; International Energy Agency: Energy Balances).

Figure 3 shows the development of the sectoral final energy consumption, using the 4-sector division of the economy. The growth in energy consumption has been very fast in the period 2000-2010. The overall trend seems to be, however, a slow-down in the growth in energy use. Even when the energy intensity of the service sector activities is low, the high total energy consumption in service sector hints that significant energy efficiency gains can be made by improving efficiencies in service activities.

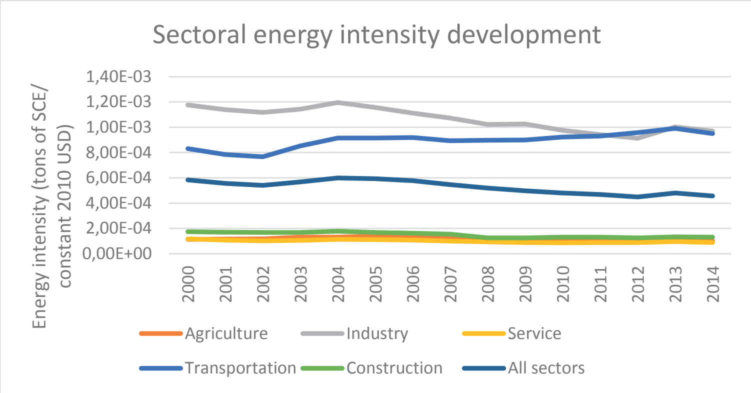

Figure 4. Development of energy intensity in China, using a 5-sector division.

Figure 5 shows the development of energy intensity (FEC/GDP) in the different economic sectors in China. The yearly energy intensity values for each sector are compared to the energy intensities of base year 2000. The transport sector shows negative energy intensity improvement measured as value over energy used, and the transport sector is getting more energy intensive. Oher sectors show significant energy intensity improvement over the period 2000—2014. The construction and service sectors have seen the greatest improvements in energy intensity, and the decrease of energy intensity for these sectors has been better than the average improvement of the energy intensity in Chinese economy.

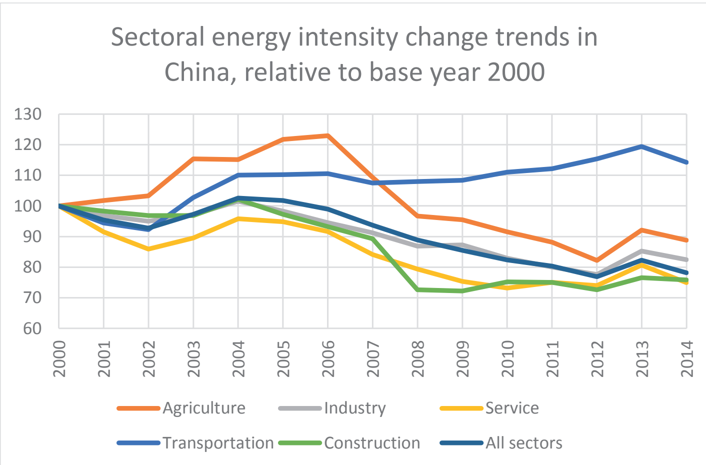

Figure 5. Sectoral energy intensity change trends in 5 sectors. Values for each sector are relative to base year 1990 value for the sector in question.

Figure 6 shows the annual change of energy intensity in the different economic sectors in China. The total energy intensity improvements for the entire economy are more than 20% in the period 2000—2014, meaning that the energy intensity is about

78% in 2014 of what is was in year 2000. The industrial sector shows fairly consistent improvement of energy intensity over the period, summing up to a 17% decrease in energy intensity.

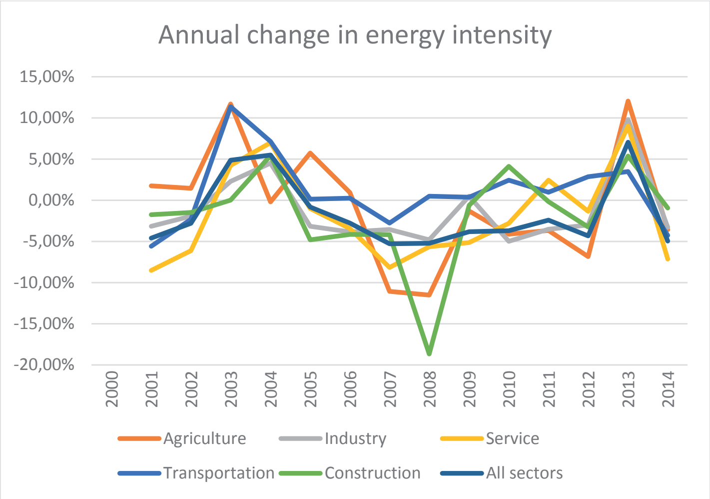

Figure 6. Annual change in the sectoral energy intensity in China.

The service sector has improved the energy intensity the most, being about 25% less energy intensive in 2014 in terms of unit of energy used to produce a unit of value. The energy intensity change trend for transport sector is quite stable but positive, meaning that the energy intensity of the transport sector is increasing. The energy intensity trend for agricultural sector is less stable in the period 2000-2014, but the overall development is that the energy intensity has decreased more than 10%. The overall picture is that the Chinese economy has made fairly consistent energy intensity improvements over the examination period, amounting to a reduction of more than 20% in energy intensity.

3. Key results of energy efficiency and decomposition analyses

3.1. The decomposition analysis results using a 5-sector breakdown

Figure 6 shows the decomposition analysis results using a 5-sector breakdown of the Chinese economy. The series display the absolute quantity, structural, intensity and total effects on energy use in relation to the base year 2000 level. The quantity effect (**Q**) embodies the effect of economic expansion or the general increase in the level of economic activity. The structural effect (**S**) reflects the impact of the structural shift of activities between the sectors. The intensity effect (**I**) is the most interesting as it captures the energy efficiency improvements as the effects of economic growth and structural change have been factored out. The total effect is the sum of the quantity, structural and intensity effects and the total change in the energy consumption from the year 2000.

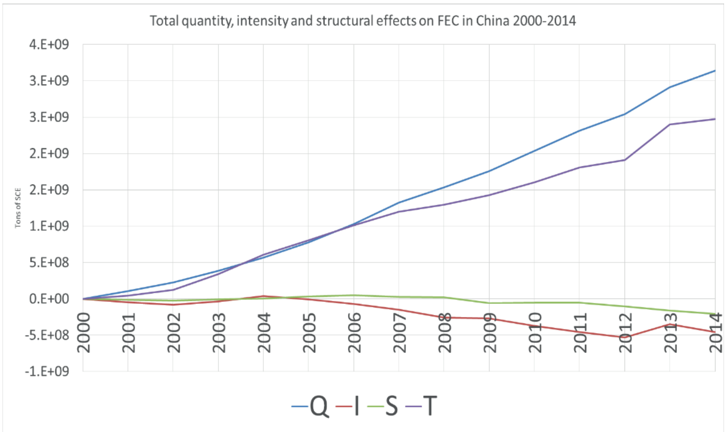

Figure 7. Total quantity, intensity and structural effects on FEC in China 1990-2014.

The total growth in energy consumption over the examination period has been about 2.5 Gigatons of coal equivalent. The quantity effect has contributed about 3.15 Gigatons of coal equivalent in terms of energy consumption growth in period 2000—2014. In China, the structural effect is unusual or different from the structural effects in EU or USA in the sense that the structural effect on energy consumption is quite small and the energy efficiency improvements measured by the intensity effect are clearly higher than the effects of structural change. The structural shift has amounted to about 0.2 Gigatons of coal equivalent of energy use reduction. The energy consumption increasing quantity effect is partially cancelled by the structural shift and the energy efficiency improvements in the whole economy, summarized by the intensity effect. The energy efficiency improvements in China amount for total of 0.46 Gigatons of coal equivalent less energy consumed. Without the structural change and the improvements in energy efficiency, the change in the energy use would have been equal to the development in the quantity effect, increasing by 3.15 Gigatons of coal equivalent. All and all, the savings through improved energy efficiency appear to be dwarfed by the speedy economic expansion.

3.2. China-LINDA analysis of outcomes of existing trends and a comparison to policy targets

As there are a great multitude of factors that can be varied by the user in the China-LINDA model, including but not limited to population growth, economic development in different sectors, energy production system details including construction of new power plants and plant efficiencies, and fuel use mix in different economic sectors, the analysis focuses on varying only general energy development. For most technical parameters of the model, such as fuel mix, power plant efficiencies, and construction of new power plants, a reasonable continuation of existing trends is assumed. For the economic development, which is central to the energy efficiency related observations made, the trend forecast relies upon the targets of the 13th five-year plan and a slowing-down trend of economic growth after the 2016—2020 period. The overall GDP growth target for the 13th FYP is 6.5% annually. The GDP growth is assumed to slow down further in the period after 2020. Table 1 presents the assumed annual sectoral GDP growth rates. With the assumed sectoral growth rates, the total growth of the economy falls into the growth track projected in the 13th FYP.

	2014-20	2020-25	2025-30
Agriculture	4.0 %	3.0 %	3.0 %
Industry	6.5 %	6.0 %	5.5 %
Transportation, communication	6.0 %	5.0 %	5.0 %
Commercial	8.0 %	7.0 %	6.0 %
Construction	9.0 %	8.5 %	8.0 %
Others	6.0 %	5.0 %	5.0 %
Total	6.5 %	5.9 %	5.5 %

Table 1. Annual sectoral GDP growth rates assumed in the China-LINDA model projection.

As for the energy efficiency development, the China-LINDA approach makes it possible to compare the existing energy intensity development trend with the targets of 13th five-year plan. Table 2 presents the annual energy intensity changes for the different economic sectors under the assumption that the targets of the 13th five-year plan are reached. Table 8 presents the annual energy intensity changes for the sectors based on the assumption that observed trends continue over the 13th five-year plan period and the energy intensity change keeps improving after that at a reasonable pace.

	2014-20	2020-25	2025-30
Agriculture	-3.0 %	-4.0 %	-5.0 %
Industry	-7.0 %	-9.0 %	-11.0 %
Commercial	-6.0 %	-7.0 %	-8.0 %
Transportation	-4.0 %	-5.0 %	-6.0 %
Construction	-12.0 %	-14.0 %	-16.0 %

Table 2. Energy intensity development compliant with the targets of the 13th FYP.

	2014-20	2020-25	2025-30
Agriculture	-1.2 %	-1.6 %	-2.2 %
Industry	-1.4 %	-1.9 %	-2.6 %
Commercial	-1.6 %	-2.2 %	-2.9 %
Transportation	1.7 %	0.0 %	-1.8 %
Construction	-2.2 %	-3.0 %	-4.0 %

Table 3. Energy intensity development projection in line with observed trends.

Varying the energy intensity growth rates and keeping the rest of the possible parameters equal in the China-LINDA model results in a range of scenarios, different in terms of final energy consumption and CO_2 emissions, among other things. Two projections are presented for final energy consumption and CO_2 emission level, based on assuming either the development along the continuation of trends (see Rable 3) or successful implementation of 13th FYP policies resulting in energy intensity targets (Chen & Jiang 2016). The projection with the successful policy assumptions is presented in table 4. Table 5 presents the projection of emissions and energy consumption under assumption of continuation of observed trends.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	8401	8630	8873	9131	9353	9557	9780	10023	10287	10506	10752	11026	11329	11662
FEC (Mtoe)	2594	2629	2667	2709	2741	2736	2736	2743	2756	2735	2724	2723	2731	2750

Table 4. Projection of CO_2 emissions and final energy consumption under the policy scenario.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	9037	9499	9987	10502	11026	11521	12042	12588	13161	13683	14230	14803	15404	16032
FEC (Mtoe)	2970	3143	3327	3523	3693	3862	4039	4226	4423	4585	4754	4932	5119	5316

Table 1. Projection of CO_2 emissions and final energy consumption under the observed trend continuation scenario

As data beyond year 2014 is not yet available, the scenarios start to differentiate before the first year (2017) shown in the tables, resulting in different values for the starting years. The difference in final energy consumption between the two scenarios for year 2030 is more than 2500 Mtoe, meaning that the energy consumption would be larger by a factor of nearly 2 in the trend scenario. The difference in terms of CO_2 emissions is 4370 Megatons, or 37%. The magnitude of differences in the projections speak on the other hand to the stringency of the Chinese energy efficiency targets and on the other hand the significant potential of energy savings in the Chinese energy systems and economy.

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Experimental analysis of a domestic trigeneration scheme with hybrid RES and desalting techniques

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Abstract

In this paper, preliminary tests of a hybrid pilot unit only based on RES, which provides electricity by coupling photovoltaic/thermal (PVT) collectors and a wind turbine (WT), sanitary hot water (SHW) coming from the PVT and evacuated tube collectors (ETC) and fresh water (FW) produced in two seawater desalting facilities (membrane distillation, MD, and reverse osmosis, RO), are presented. Pilot plant design was previously modelled by TRNSYS, including a sensitivity analysis of some free-design variables, such that the ETC surface, PVT and ETC tilt, water storage tank, batteries capacities, and mass flow rates delivered to the SHW service and/or feeding the MD unit. First tests show that daily assessment of fresh water, SHW and power produced with the optimized design gave a good coverage of water and energy demands for a typical single family home. Moreover, the advantages of using hybrid schemes for powering and desalting, and the main drawbacks found within the pilot unit operation will be described.

1. Introduction

The search of innovative and sustainable solutions to provide secure energy and water, especially in isolated areas (where power and water networks induce economic and environmental extra costs) by integrating existing technologies is a way that should be deeply explored. This paper is one example of an integrated multipurpose scheme fully supplied by RES, in its preliminary implementation for further appliance in the domestic sector.

With solar energy, both electricity and thermal energy can be obtained through the use of a photovoltaic-thermal collector (PVT) (Liang et al, 2015). This hybrid collector integrates features of single photovoltaic and solar thermal systems in one combined product. Due to electricity and thermal energy production of PVT, economic savings are twice than the economic savings found utilizing the single PV module (Buonomano et al, 2016). Anyway, in case of not having abundant solar irradiance, a wind-solar hybrid system is commonly utilized in isolated areas. So, electricity generated can greatly meet the load demand because one energy type can offset the shortfall of the other (during the day may occur that high solar irradiation and relatively low wind energy, while by night occurs the contrary, Huang et al, 2015).

On the other hand, one of the major problems found in dry and/or isolated areas is water scarcity. Nevertheless, the areas with the highest need of drinking water usually exhibit the highest solar energy presence. Thus, a distillation technique like membrane distillation (MD) is appropriate to be fed by solar energy for small capacities and isolated areas (Zaragoza et al, 2014; Shim et al, 2015). However, distillation techniques have usually higher energy consumptions than membrane techniques like Reverse Osmosis (RO) or electrodyalisis (ED, for brackish waters), which only consume power. As the PVT both provides power and heat, distillation and membrane processes could then be easily combined here.

The state of the art denotes that, apart from producing RES based-energy or water with hybrid techniques separately (Cherif and Beldhadj, 2011; Weinar et al, 2011; Iaquaniello et al, 2014), there are very few examples of tri-generation or poly-generation schemes involving seawater desalination and RES, and even less if we consider the hybrid production of any of those demands. Calise et al (2014) proposed a poly-generation system based on PVTs, a LiBr-H_2O chiller, and a MED distiller, with a back-up biomass heater. A similar scheme could be optimized in its design and operation if conventional energy sources are neglected (Rubio et al, 2011). But both cases did not include any experimental test. From the previous analysis, it can be observed that the combination of hybrid techniques for both RES and desalination, which also includes SHW, has not been tested in detail yet. Thus, this paper presents the preliminary results of a double hybrid scheme (Wind/PVT+SHW+MD/RO) which allows providing power, SHW and fresh water at a much reduced demand scale in isolated areas. As those results indicate, this hybridization is a technically possible solution and its profitability will depend on alternative costs to provide water and energy by a network or local transport.

2. Equipment

The plant layout of the pilot unit, as well as the definite design and predicted productions of power, SHW and desalted water by the MD and RO unit was presented in a previous paper (Acevedo et al, 2016) with the help of TRNSYS simulations. The paper also included a cost estimation of the water, power and SHW produced by this pilot unit according to the investment required and life time expected. The pilot unit has been installed at the tile roof of an industrial unit at the University of Zaragoza (Campus Rio Ebro), and it is actually isolated from the grid.

2.1 External RES supply

Solar loop consists of four PVT collectors (230 W_p, 1.63 m^2 each) and one Evacuated Tubes Collector (ETC) of 3 m^2. The PVTs are divided in two sets connected in series to the ETC, and each PVT set contains two collectors in parallel. PVTs are connected to a battery by means of a MPPT (maximum power point tracker) device. A solar energy fraction is also transformed into thermal energy. Inside of the hydraulic circuit, the water-glycol (70/30%) fluid is sent to a 325 L storage tank by means of a heat-exchanger/pump system working upon a hysteresis loop with respect to the tank temperature. Two safety systems were included to avoid overheating: one aerotherm and the self-emptying of the tank.

A 400 W_p micro wind turbine (μWT) was also connected in parallel with the two batteries in serial (250 Ah, 12 V). Figure 2.1 shows the external equipment.

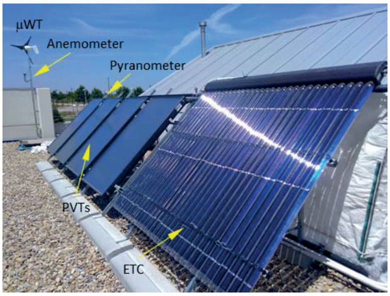
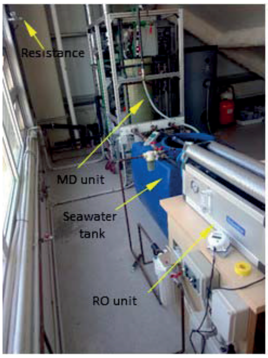


Figure 2.1: Detail of the μWT, PVTs and ETC of the pilot unit.

2.2 Internal power-based demands

Power generated by the PVT and the μWT is stored in batteries. From those batteries, most of that power is converted into AC by means of a regulator/inverter, in order to feed the pumps: MD unit (80 W_p), solar loop (50 W_p) and heat exchanger (HX-MD) to heat the MD unit (60 W_p) and the aerotherm (30 W_p). The RO unit consumes DC with very low specific consumptions (110 W_p, 35 L/h) and acceptable salinities (< 600 ppm). Finally, a potentiometer has been installed in the electric cabinet and is linked to an electric resistance of up to 1 kW_p, in order to simulate the internal demand of a dwelling. Figure 2.2 (left) includes the desalting units as well as the electric resistance; on the right the electric cabinet, hot water tank, expansion vessels and batteries are shown.



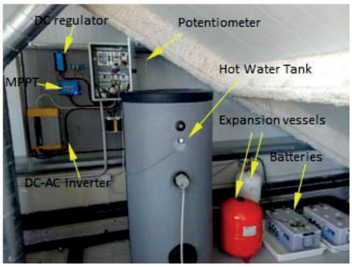


Figure 2.2: Detail of the RO and MD units (left) and electric cabinet, hot water tank and batteries.

2.3 Internal heat-based demands

Thermal energy stored at the tank could be shared to supply the MD unit (20 L/h, and produce a very pure distillate, <2 ppm), by means of the abovementioned HX-MD and the SHW demand to a dwelling. The MD is a commercial PG (Permeate Gap type) MD module and contains a spiral wound desalination membrane with a total exchange area of 10 m^2, with their corresponding condenser, distillate and evaporator channels (Winter et al, 2012). Usually, the set-up temperature to feed the MD is 70ºC, but lower temperatures could be maintained with reduced distillate rates.

Flows to the MD and SHW supply are controlled by a proportional commanded valve (V). As hot water discharge from the tank is above the service temperature (45ºC), a heat balance is then included to know the real supply of SHW to the consumers. Any discharge is restored by drinking water from the network. Additionally, the MD includes a cooling circuit (a new HX fed by cool water from the network, HX-CW) to avoid excessive overheating of the seawater tank, in case of connecting desalted seawater and brine discharges to that tank (a quite common practice in pilot units with lab prepared seawater). Note that discharge brine from the MD is about 7ºC higher than seawater feed. Figure 2.3 (left) shows those hydraulic connections.

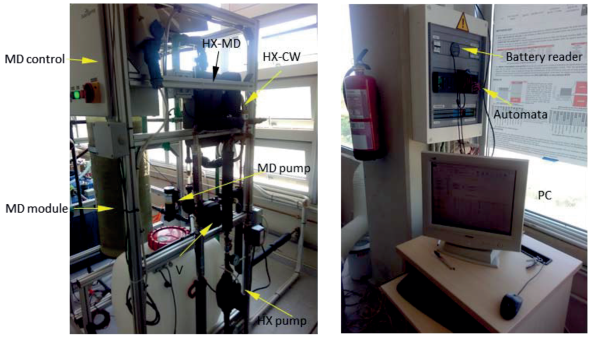


Figure 2.3: Detail of the internal hot water circuits (left) and control.

2.4 Control system

The complex hybrid scheme mounted includes a sophisticated control and monitoring system in order to manage the pilot unit. Three temperatures were taken from the solar loop, two temperatures in the SHW tank (to check if stratification exists), and eight measurements at the MD inlets/outlets. Inlet and return from the HX-MD are also measured to estimate the MD thermal energy consumption. Seawater tank and outside temperatures are measured as well. All temperatures were measured by PT-100 sensors (+/-0.2ºC). A pyranometer for solar irradiation (+/-2%) and an anemometer were also installed. Finally, a software is connected to batteries in order to know the voltage, incoming current and state of charge (SOC, %), among others. All those measurements were taken every minute, and they are recorded by an automata, which also controls valves, pumps and any other safety systems.

Only liquid flow rates were visually measured by five flowmeters (solar loop, distillate in MD, permeate in RO, hot water flow to serve HX-MD and SHW respectively), their accuracy is estimated after calibration in a range of +/-2%. Finally, conductivity of seawater tank, distillate and permeate are measured by different conductivity meters, but only the most changing one (distillate in MD) is controlled by the automata and managed by a PC (see Figure 2.3, right).

3. Experimental tests

In the period from November 2016 to May 2017, experimental validation of the RO, MD, PVT, μWT and batteries was performed. Especial emphasis was made on the MD tests according to the effect on its productivity of some parameters like the flows of seawater to the condenser and hot water feeding the MD throughout the HX-MD, as well as the seawater and hot water tank temperatures (note that the driving force of MD is the ΔT between the hot and cold sides of the MD membrane channels). From May 2017, complete tests started, including the power, desalted water and SHW supply to hypothetical consumers.

3.1 Following the meteorology

In the first complete trigeneration trials set (May 2017), existing climatology was taken into account in order to switch on and off the major consumers of the plant (RO, MD, SHW and power demand service) according to the battery SOC and temperature in the water tank. This period has been characterized by a rather good but very instable irradiation (G) a low wind speed (v). Figure 3.1 shows a very representative day (10/05/2017), in which the day started with a partially cloudy period, even with a light rain, up to noon. As the RO unit was switched on (Fp), and the power demand was stablished on about 500 W (Wd), the batteries were decreasing its SOC below the 80% with a rather constant voltage yet (V). Thus, and considering that sunshine appeared, RO is stopped but MD is put into operation (Fd), thereby substituting permeate by distillate. The power demand is maintained, since irradiation is high at this moment. But at around the fifteenth hour, suddenly a storm strongly decreased irradiation, and therefore distillate from MD is also drastically reduced. At this point, and although one hour later the sun was again appeared, MD was stopped but SHW (Fac) was served during almost one hour, since the tank temperature (mTQ) is above the temperature service.

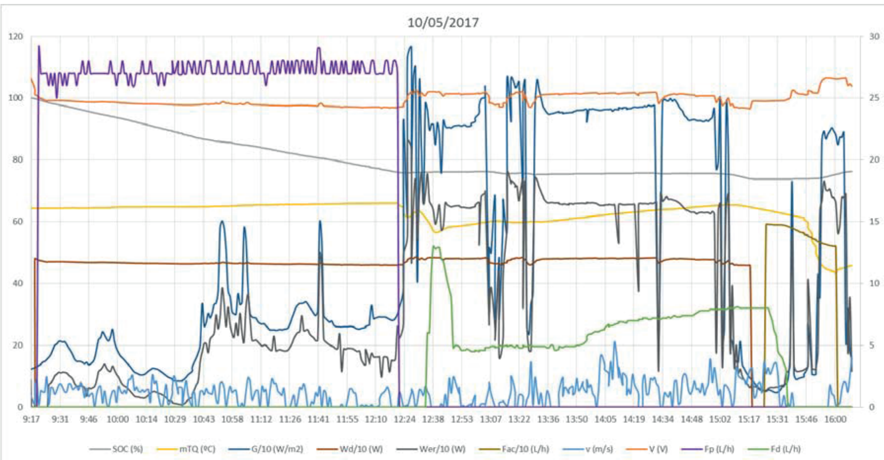


Figure 3.1: Experimental test (10/05/2017) adapted to existing meteorology.

3.2 Following the internal demands

In previous section, the production was accommodated to external conditions, but it is clear that the plant should hourly provide the predicted consumer profiles of water, power and SHW. The electric and water demand considered in this investigation were based on a single family home in Spain. The electric demand from this kind of home is about 2422.2 kWh per year (Villagarcía, 1998). On the other hand, the total fresh water demand is estimated in 106.4 cubic meters per year, and SHW demand in 37.2 m^3/y (González et al, 2008). Hourly characterization of those three demands was then estimated for each day of the year (BOE, 2016) according to existing regulation.

Thus, from June 2017 the pilot unit is operating following the hourly demands of power and SHW. In case of desalted water, it is assumed that it exits a water tank to supply the typical consumption of a day, thus the RO+MD operation should only have to fulfill the daily requirements of freshwater for the single family home. Next figure shows a representative sunny day (05/07/2017, see Figure 3.2), in which the MD operation (when the water tank had enough temperature) provoked a serious overheating in the seawater tank (>33ºC), thus the RO unit was stopped to protect the membranes. Anyway, most of the freshwater demands, as well as SHW and power demands were perfectly covered every hour, without major alarms detected in the SOC or tank temperatures. Next table resumes the degree of coverage during the test and with respect to the daily demand, from a selected set of tests (> 4 hours): note that except for the first one, RO was forced to stop due to the unexpected overheating of the seawater tank.

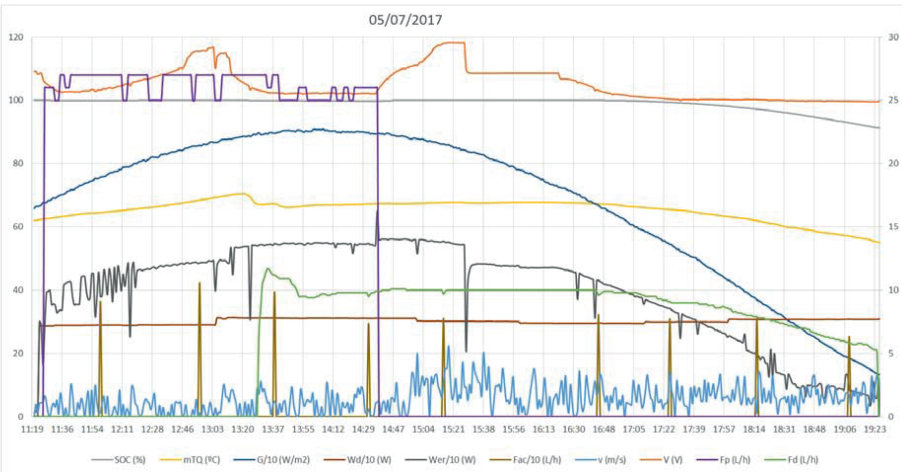


Figure 3.2: Experimental test (05/07/2017) adapted to fulfilling the hourly demands predicted.

Table 3.1: Degree of coverage (%) of some tests which lasted more than 4 hours.

Test	07/06/17	12/06/17	05/07/17	07/07/17	11/07/17	13/07/17
Period (h)	15-19	10-16	11-19	11-15	11-16	13-20
Pow., test	96.3	99.5	101.11	80.89	99.64	86.04
Pow., day	18.8	28.2	41.26	21.92	27.90	35.11
Wat., test	230.5	173.0	117.83	125.72	159.10	85.23
Wat., day	50.5	55.2	50.16	35.75	44.70	36.23
SHW, test	344.3	97.8	121.37	142.03	227.17	234.72
SHW, day	75.4	30.6	51.66	40.09	63.36	99.91

4. Conclusions

The hybrid pilot plant based on RES erected allows to perfectly cover the demands of power, SHW and desalted water by the MD and RO in spring and summer. Installed control permits a flexible and safe management of the plant according to diverse objectives, including the economic profitability of its operation depending on external power, fuel and water prices.

Further tests are yet required in autumn or winter season, especially to check the range of self-power produced. Up to now, major problem found in lab tests has been the additional cooling (apart from the incorporated by the MD unit) required in summer due to the seawater tank overheating, in order to maintain the RO operation and to increase the MD productivity (higher available ΔT).

Acknowledgement

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Exergy analysis of the transient simulation of a renewable-based trigeneration scheme for domestic water and energy supply

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Abstract

Exergy analysis is proposed as a complementary method for the analysis and better understanding of the efficiency of a trigeneration system based on renewable energy sources that is being erected in Zaragoza (Spain). The system combines photovoltaic/thermal collectors (PVT), evacuated tube collectors and a wind turbine and produces electricity, hot water and fresh water for a single family house. The system includes two desalination technologies (reverse osmosis and membrane distillation) as well as energy storage in a hot water tank and batteries.

The application of exergy analysis has been adapted to the transient nature of the trigeneration system analyzed, and two levels of detail are proposed. First of all, it is applied in hourly basis, which allows to compute in detail how efficiency evolves in the short term, what is useful for improving system operation. This is done by applying new types for exergy calculation that have been modeled in TRNSYS. As a second level of detail, it is proposed to apply indicators (aggregated exergy and aggregated efficiency) that summarize the system behavior during a longer period of time (monthly basis).

1. Introduction

The use of solar and wind energy can constitute a sustainable option for providing electricity and sanitary hot water or even fresh water (Trujillo et al., 2014). In particular, photovoltaic-thermal (PVT) collectors integrate the production of both electricity and hot water, improving the efficiency and reducing the required roof surface (Liang et al., 2015; Astea et al., 2015). Since not always it is possible to have abundant wind or solar irradiance, wind-solar hybrid systems are usually proposed for isolated systems (Bakic et al., 2012; Huang et al., 2015). Regarding water production, membrane distillation operates at temperatures about 70-90 ºC (Raluy et al., 2012), so that it is suitable for being integrated with evacuated tube collectors.

Besides, exergy analysis (Szargut, 2005) is able to detect and quantify in detail where and when irreversibility occurs and, thus, it is useful in the search for new improvements of energy intensive systems. Furthermore, it quantifies in the same units streams of different nature, what makes it very convenient for the assessment of polygeneration systems. For instance, exergy analysis of PVT systems has been developed by Saloux et al. (2013), Liu et al. (2013) have applied this approach to the assessment of nanofiltration seawater desalination and Calise et al. (2015) developed an exergy and exergoeconomic analysis of a polygeneration system based on parabolic collectors, biomass boiler, absorption chiller and multi effect distillation.

In this paper, the exergy analysis of the transient operation of a renewable energy-based polygeneration system that includes PVT, evacuated tube collectors and a wind turbine, with two water production technologies (reverse osmosis and membrane distillation) is developed. Data for exergy calculations is obtained from TRNSYS simulations developed by the authors (Acevedo et al., 2016).

2. System description and exergy analysis

The aim of this section is to present the framework needed for obtaining the exergy-related parameters which constitute the results of the paper. First, the polygeneration system is presented. Afterwards, a brief outline of the TRNSYS model is made. Finally, equations applied for exergy calculations are summarized.

2.1 System description

The system analyzed is depicted in Figure 2.1, and consists of five subsystems: solar loop, sanitary hot water (SHW) loop, membrane distillation (MD) module, reverse osmosis (RO) module and power loop. The solar loop includes four PVT collectors (1.63 m^2 each) divided in two sets (PVT 1-2 and PVT 3-4), as well as an evacuated tube collector (ETC, of 2 m^2) and the pump needed for water-glycol circulation. SHW loop comprises a 325 l hot water tank and the required pumps and valves. The membrane distillation is driven by hot water from the tank trough a heat exchanger. It is permeate gap membrane distillation (PGMD) type and can produce 20 l/h under suitable thermal conditions. The reverse osmosis module produces 35 l/h and consumes 110 W. Finally, the power loop includes the electric production of the PVT collectors (4 x 240 W) and the micro wind turbine (400 W), a set of two batteries (250 Ah and 12 V), power control and electric demands (pumps, RO and electric demand of the home).

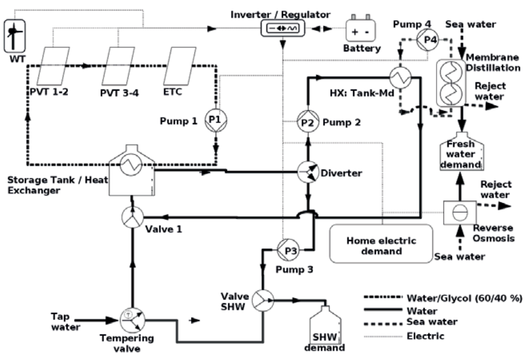

Figure 2.1: General structure of the polygeneration scheme.

2.2 Modeling

A detailed description of the system modeling by using TRNSYS can be found in a previous paper (Acevedo et al., 2016), including an ad-hoc model of MD unit. Weather conditions of plant location (Zaragoza, Spain) have been obtained from Meteonorm database[1]. Demands of fresh water and sanitary hot water have been determined as recommended in (Gonzalez et al., 2008) and power demand of the home has been fixed according to standards (Villagarcía, 1998). Results of the simulation include the hourly evolution of matter and energy flows within the system during a year for different cases; among them, the case identified as the best one (due to the higher water production by MD) has been chosen in this paper for exergy calculations.

2.3 Exergy analysis

Dedicated TRNSYS types have been developed to calculate exergy flows related to matter and energy flows of the analyzed system. Exergy of sun radiation is obtained by applying the approach proposed by Petela (1964):

$$\dot{B}_{rad} = IA_a\left(1+\frac{1}{3}\left(\frac{T_0}{T_s}\right)^4-\frac{4}{3}\left(\frac{T_0}{T_s}\right)\right)$$

Where I is the solar intensity, A_a is the surface area, T_0 is the reference temperature and T_s is the temperature of surface emitting radiation (in K). In the case of wind, exergy is equal to kinetic energy:

$$\dot{B}_{wind} = \frac{1}{2}\dot{m}v^2 = \frac{1}{2}A\rho v^3$$

Where $\dot{m}$ is mass flow rate (of air, in this case), v is velocity, A is area and ρ is density. Physical exergy of water and water-glycol streams is calculated taking into account that TRNSYS does not consider explicitly pressure drops and assuming incompressible flow with constant specific heat:

$$\dot{B}_{ph} = \dot{m}c_p\left(T-T_0-T_0c_pln\left(\frac{T}{T_0}\right)\right)$$

c_p is specific heat at constant pressure, T is temperature of the flow, and T_0 is reference temperature, both in K. Finally, specific chemical exergy of salt-water flows, is calculated by the following formula (Liu et al., 2013):

[1] http://www.meteonorm.com

$$b_{ch} = N_s R T_0 ln \frac{N_s}{N_s + \sum\left(\frac{\beta_i C_i}{\rho MW_i}\right)}$$

$$N_s = \frac{1000 - \sum\left(\frac{C_i}{\rho}\right)}{MW_s}$$

Where C_i is the weight concentration of the i^{th} component per liter of solution (g/l), MW_s and MW_i are the molecular weights of the solvent and i^{th} component, respectively, and β_i is the number of particles generated by the dissociation of the i^{th} component in the solution.

Once exergy flows have been calculated, efficiency of components is obtained by dividing exergy of product into exergy of fuel.

$$\eta_b = \frac{\dot{P}}{\dot{F}}$$

It is also interesting to calculate aggregated values for a given period of time (e.g. one month). In this case, fuel and product are expressed in energy values and calculated by integration during the considered period of time, and efficiency becomes:

$$\eta_{b,av} = \frac{P}{F}$$

3. Results

Exergy analysis has been applied by considering two time scales: detailed time evolution of selected days (hourly basis) and aggregated values (monthly basis).

3.1 Detailed time evolution

Figure 3.1 shows the time evolution of product, fuel and efficiency of the first set of PVT panels during a selected summer day (19^{th} July or the 200^{th} day of the year). The fuel is the exergy of sun radiation, whereas the product is the increment of exergy of water heated in the collector, plus electricity produced. It can be seen how not only fuel and product, but also efficiency, are higher in the central hours of the day. A similar graph for wind turbine for a given winter day (30^{th} January) is depicted in Figure 3.2. In this case, the time evolution of the variables is strongly dependent of the day; for the chosen example, it can be seen how wind blows at night, morning and evening, but not in the afternoon.

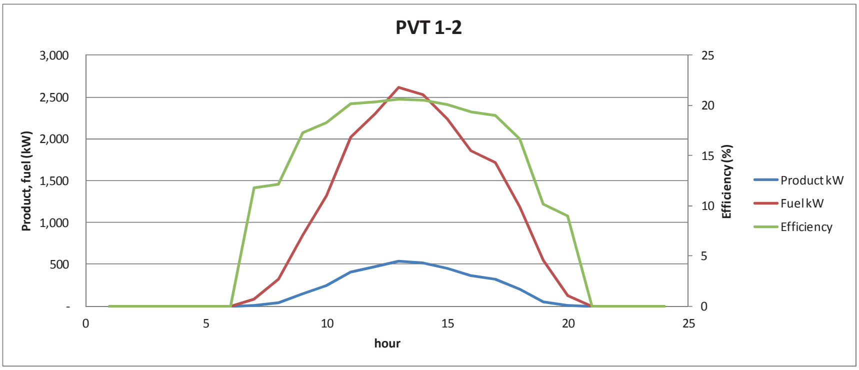

Figure 3.1: Time evolution of fuel, product and efficiency of PVT collector in an example summer day.

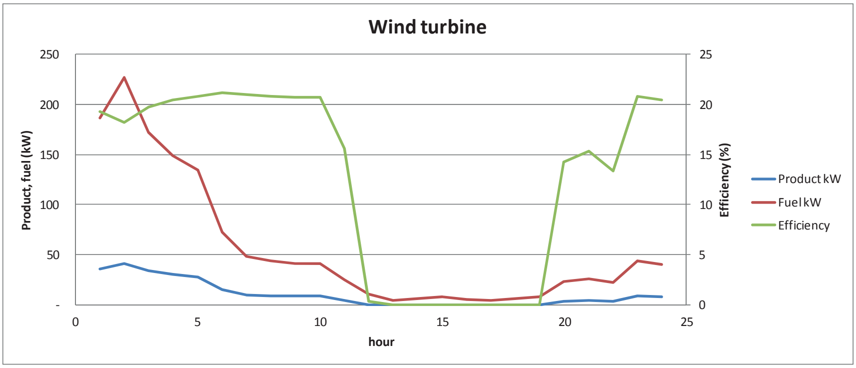

Figure 3.2: Time evolution of fuel, product and efficiency of wind turbine in an example winter day.

3.2 Aggregated monthly analysis

The analysis presented in the previous section is interesting for observing details of system behavior. However, in order to assess global system efficiency, it is more convenient to apply aggregated variables, for instance, in monthly basis. This analysis appears in Figure 3.3 for the first set of PVT panels. Bars in the graph show how the exergy of fuel (total bar length) is either transformed into useful stream (product) or destroyed (irreversibility). It should be noted that, due to the time integration, now fuel, product and irreversibility appear not in power units but in energy units (GJ). Aggregated efficiency is represented by a line. It can be seen how the higher values of efficiency appear in summer, but the lowest appear not in winter but in spring and autumn. This effect is due to the fact that efficiency is affected by two different causes: on one side, hot temperatures reduce thermal losses, but also reduce production of electricity. Figure 3.4 shows the same graph but for evacuated tube collectors. It can be seen how higher efficiency appear in summer due to lower losses and also higher temperature of heated water (higher ratio exergy/energy); besides, its efficiency is much lower than that of the PVT panels.

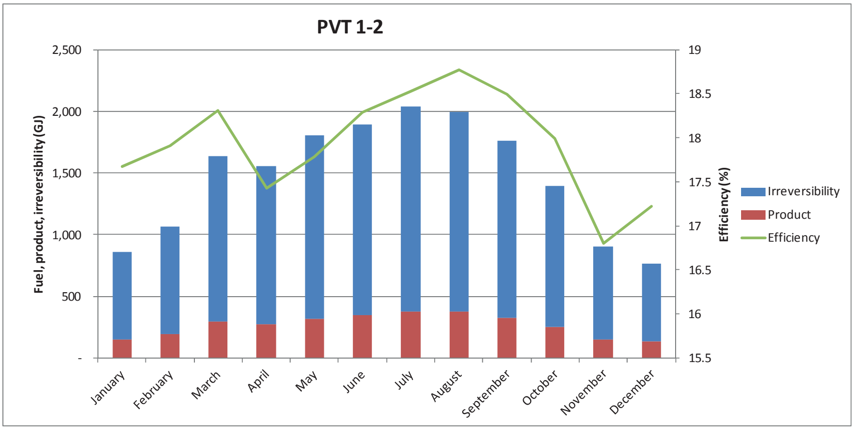

Figure 3.3: Aggregated monthly fuel, product, irreversibility and efficiency of PVT collector 1-2.

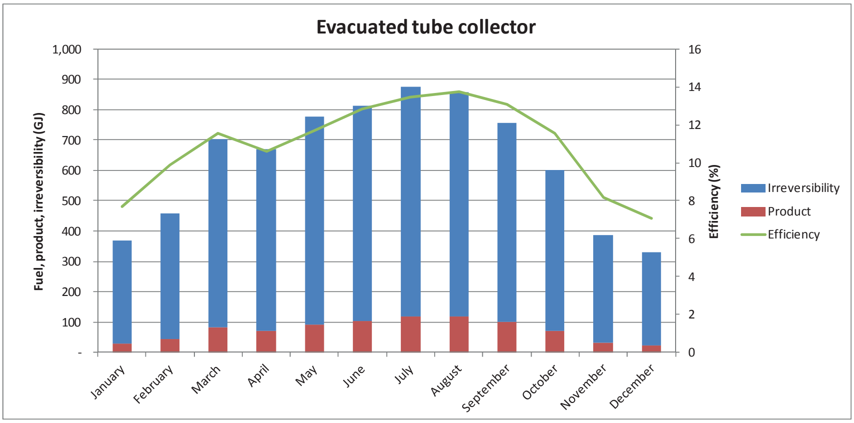

Figure 3.4: Aggregated monthly fuel, product, irreversibility and efficiency of evacuated tube collector.

Behavior of hot water tank is represented in Figure 3.5. Efficiency of this component is around 40-45%, being lower in hotter and colder months. This fact can be explained by taking into account that higher temperatures means higher thermal loses but also lower irreversibility in the heat transfer from hot water from the thermal collectors to stored water in the tank. It should be noted that the product of the tank is the exergy of hot water leaving it minus exergy of entering cold water, and the fuel is the exergy drop of hot water coming from the solar panels. In other words, the term of exergy accumulation has not been considered, what is only possible when the analysis is made for long periods of time (such as one month). Finally, Figure 3.6 shows the values of fuel, product, irreversibility and efficiency of membrane distillation unit. It can be seen that this unit only can work at high load in hot months. Besides, its efficiency is quite low, what makes it only interesting when it is properly integrated with a low temperature heat source.

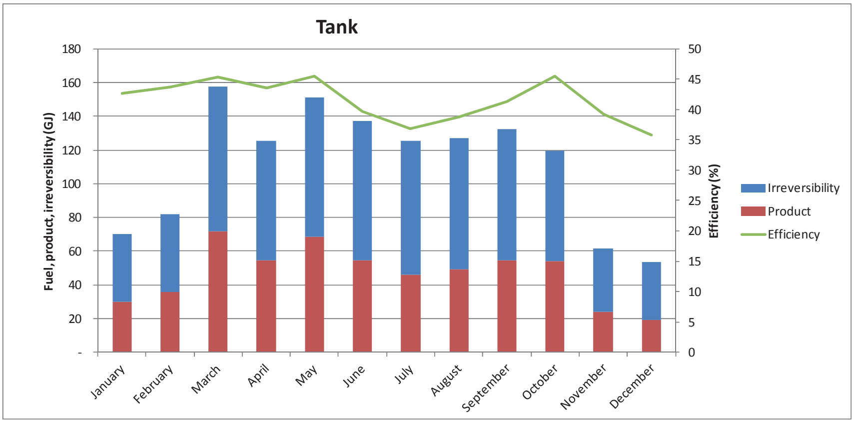

Figure 3.5: Aggregated monthly fuel, product, irreversibility and efficiency of hot water tank.

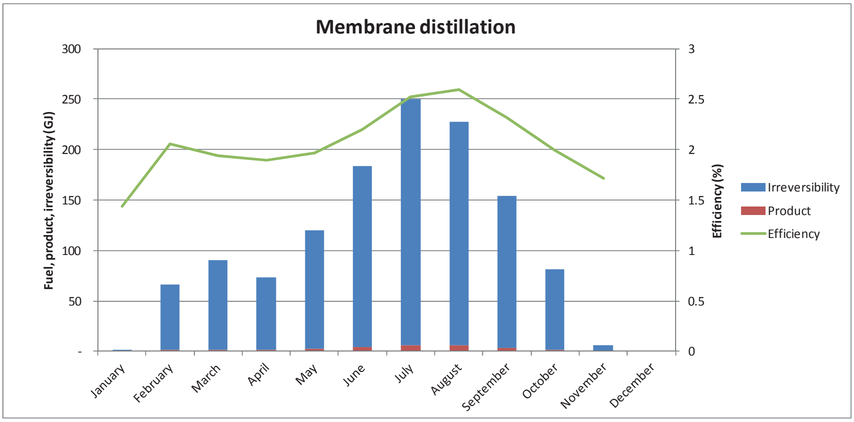

Figure 3.6: Aggregated monthly fuel, product, irreversibility and efficiency of membrane distillation unit.

4. Conclusion

Exergy analysis of the transient operation of a polygeneration system producing electricity, fresh water and hot water from PVT and EC panels and a wind turbine has been presented. The study has been made by using simulation results obtained by a

TRNSYS model of the system. Two time scales have been applied: detailed analysis with hourly evolution of the variables and aggregated analysis in monthly basis that summarizes in a single graph behavior during a year of the analyzed component. Results show that highest irreversibility appear in the collectors, what could be expected since they produce heat at low temperature; in this sense, PVT panels have much higher efficiency due to the joint production of hot water and electricity. A relevant source of irreversibility is the need of driving MD unit at suitable temperature, what in the present design is made trough several steps (collectors, hot water tank and heat exchanger); a direct connection avoiding the tank would lead to lower irreversibility but would also increase the complexity of operation and control. Next step of the research will be the application of the analysis to different operation conditions in order to compare them from the exergy point of view (what is straightforward due to the developed TRNSYS types), the analysis of actual operation data (the simulated plant has now been erected in Zaragoza and the first operation test have been made), and the calculation of exergy costs. The latter can be done by using aggregated variables, what allow to overcome the effect of accumulation.

Acknowledgement

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Exporting volatility through market integration: the case of Sardinia

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Abstract

In this paper, we estimate volatility transmission patterns before and after the inauguration of a new cable linking electricity market zones that are rich in intermittent renewables. Using daily wholesale electricity prices in Sardinia and in two neighbouring Italian market zones in the 2005-2015 time window, we focus on the effects of the SAPEI cable, fully operational since March 2011. VAR-GARCH-in-mean estimates indicate that the SAPEI cable allowed for stronger volatility transmission from a net importing zone, such as Sardinia, than towards the island, and for higher conditional correlations between prices across the cable. Moreover, volatility from Sardinia is associated with lower mean prices in the neighbouring zones.

1. Introduction

The Sardinian wholesale electricity price has historically been above the average national price, signalling a chronic supply shortage in a region characterised by scarcity of hydropower sources. The HVDC interconnection inaugurated in March 2011, named SAPEI (SArdegna-PEnisola Italiana), has mitigated this issue, yet the new link has come into operation while investments in intermittent renewables were soaring on the island, causing concerns of volatility transmission from Sardinia to the Italian mainland.

In this paper, thus, we estimate and compare volatility transmission effects before and after the inauguration of the SAPEI cable, through multi-variate VAR-GARCH-in-mean models, using daily data on electricity prices in Sardinia and in the other IPEx market zones in the 2005-2015 time window. Reference papers include the multivariate GARCH analysis of Worthington et al. (2005) and Higgs (2009) on Australian data, as well as Ciarreta and Zarraga (2015), de Menezes and Holler (2015), Gianfreda et al. (2016), on European power markets. GARCH-in-mean has been applied to electricity markets by Liu and Shi (2013) and Efimova and Serletis (2014). Italian prices have been analyzed, among others, by Gianfreda and Grossi (2012), Ardian et al. (2015), Bigerna et al. (2015), and Sapio and Spagnolo (2016).

The results show that while conditional correlations between Sardinia and South prices converge to unity after the SAPEI cable, volatility transmission from Sardinia, a net electricity importer, increases after the inauguration of the cable, and is stronger than from a net exporter such as the South zone.

The next Section 2 describes the data and the econometric model. The main findings are summarized and discussed in Section 3, before the concluding remarks offered in Section 4.

2. Data and methods

Data on the wholesale day-ahead zonal electricity prices (in Eur/MWh) have been collected from the IPEx website (www.mercatoelettrico.org) for the period Jan 1, 2005-Jul 31, 2015. These data are originally recorded with a hourly frequency, as each day, market participants can submit bids and offers valid for each hour of the next day, used by GME to clear the market using a merit order rule.

Optimal dispatch solution of the market clearing involves the calculation of zonal prices, which may differ when lines are congested, in which case the Italian grid is segmented into up to 6 market zones (North, Center-North, Center-South, South, Sicily, and Sardinia). Based on GME Annual Reports from 2005 to 2014, one can identify the direction of trade flows across zones. Sardinia, and Sicily are characterized, on average, as net importers; North is a net exporter to Center-North; Center-North is a net importer from both North and Center-South; Center-South is a net importer from South and a net exporter to Center-North; South exports to both Sicily and Center-South (see Ardian et al. 2015).

The econometric analysis is performed on the time series of daily averages of zonal electricity prices. We focus on the Sardinia zonal price $p_{i,t}$ (“i” stands for “island”); on $p_{n,t}$, defined as the load-weighted average of Nord and Centro-Nord prices; and on $p_{s,t}$, the load-weighted average of Sud and Centro-Sud prices. A dummy, taking unit value since March 17, 2011, takes up the effects of the new SAPEI cable. Daily oil prices (Brent crude oil) and gas prices (Zeebrugge, TTF) have been sourced from Eikon, a Thomson-Reuters database. For each variable, 3864 daily data points are available.

The descriptive statistics (not presented here) show that all zonal prices decreased after the cable, both in mean and median, partly due to the great recession. The fall in electricity demand on the island, along with the boom in renewables, apparently has allowed the Sardinia-South interconnection to work without running into congestion too frequently. Yet there is a slight increase in the standard deviation in both Sardinia and South presumably because of the larger renewables penetration.

Unit root tests (Augmented Dickey-Fuller, Phillips-Perron, KPSS) performed on the time series of zonal electricity prices indicate that the time series can be considered mean-stationary. Yet, because of spikes and seasonal effects we have treated the zonal log-prices by means of the recursive filter on (log-)prices (RFP) proposed by Janczura et al. (2013).

We represent the first and second moments of electricity prices in Sardinia, North and South of Italy using a VAR-GARCH(1,1)-in-mean process selected based on Ljung-Box portmanteau tests:

$$x_t = \alpha + w_t + \beta x_{t-1} + \theta h_{t-1} + \delta f_{t-1} + \beta_7 x_{t-7} + u_t \quad (1)$$

where x_t = (ln $p_{n,t}$, ln $p_{i,t}$, ln $p_{s,t}$) - respectively, log-prices in North, Sardinia, and South at time t. The oil and gas prices are included in f_t = (ln $p_{oil,t-1}$, ln $p_{gas,t-1}$). The GARCH-in-mean parameters allows for Sardinia i,n i,s volatility effects into mean log-prices in North ($\theta_{i,n}$) and South ($\theta_{i,s}$). The parameters vector of the mean log price equation is defined by the constant α = (α_n , α_i , α_s), the weekend dummy w_t. The vector of residuals u_t = ($u_{n,t}$, $u_{i,t}$, $u_{s,t}$) is trivariate and normally distributed with zero mean and a conditional variance covariance matrix $H_t = C'_0 C_0 + A' U A + G' H_{t-1} G$ where C_0 is upper triangular, the A matrix collects the own- and cross-zonal ARCH effects, and the G matrix includes the own- and cross-zonal GARCH effects. The generic element of G is g_{jk}, where j and k denote generic zones. Similarly, a_{jk} is the generic element of A. In order to account for the possible effects of the new SAPEI cable, in H we include a dummy variable with a switch on 17 March 2011, i.e. on the day of the new cable starting activity. The parameter is the matrix H, associated to the dummy, are denoted by * (e.g. a_{jk}*, g_{jk}*).

The BEKK representation adopted here by construction that the covariance matrix in the system is positive definite, and is preferred over the DCC because we deal with a small system of just three price equations. The standard errors are calculated using the quasi-maximum likelihood methods of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals.

3. Results

The estimated coefficients of the VAR-GARCH(1,1)-in-mean model, with the associated robust standard errors, are presented in Tables 1 (conditional mean equation) and 2 (conditional variance equation), both in Appendix.

Table 1 shows positive and significant first-order autocorrelation in North and South, similarly sized (slightly below 0.5 in both cases), except for the North-Sardinia link, the one characterised by tighter transmission constraints. Cross-zonal correlations are all positive and significant, yet they are dampened in some links. For instance, $\beta_{in}{}^*$, $\beta_{si}{}^*$, $\beta_{ns}{}^*$, and $\beta_{sn}{}^*$ are similar in magnitude as pre-cable coefficients β_{in}, β_{si}, β_{ns}, and β_{sn}, but opposite in sign. In the more strongly integrated post-cable market, zonal prices are expected to move together. Hence, removing trends and seasonals, as we do, leaves only a small residual cross-correlations.

Table 1, however, shows contrasting results concerning the GARCH-in-mean effects. Coefficient θ_{is}, the effect of Sardinian volatility on Southern mean log-prices before the cable, is positive and significant. Yet, $\theta_{is}{}^*$ is negative and significant, so that the overall effect, taking account of the cable, is negative. Hence, higher volatility in Sardinia is associated with price mitigation in the South only after the SAPEI cable. Instead, we find negative and significant effects of Sardinian volatility on Northern mean log-prices throughout the whole sample period (both θ_{in} and $\theta_{in}{}^*$ are negative).

As to control variables, we find no significant deterministic weekend effects, perhaps because the price in each zone is significantly correlated with its seventh lag. Gas prices display positive, significant, and similarly sized coefficients in all three zones, but this is not the case for oil prices.

Table 2 focuses on ARCH effects and GARCH effects. In interpreting the results, notice that the sign of the coefficients included in the A and G matrices are not relevant, as both matrices enter the H matrix through quadratic forms. Hence we only focus on statistical significance. Table 2, comparing GARCH effects before and after the cable (g_{is} and $g_{is}{}^*$), both statistically significant, shows that the effect of the conditional variance in Sardinia on the conditional variance in the South was increasing after the cable. $g_{is}{}^*$, measuring the effect of the conditional variance from a net importer, is also stronger than $g_{si}{}^*$, the estimated GARCH effect from the South (a net exporter) to Sardinia.

Finally, the ranking between Sardinia-South and Sardinia-North GARCH effects is not clear: g_{in} = 0.569, higher than g_{is} = 0.433 before the cable, but comparing the coefficients after the cable, there seems to be a stronger volatility transmission from Sardinia to South. Hence, there is some indication that volatility transmission between two zones that are rich in renewables (Sardinia and South) is stronger than between zones that differ in that respect (Sardinia and North) and with more limited transport capacity.

The results on ARCH effects are along the same lines. The effect of squared errors from Sardinia to South seems stronger, yet there is no significant change after the cable (a^*_{is} not significant).

Finally, the conditional correlations between Sardinia and South log-prices (Figure 1, upper panel, in Appendix) derived from the VAR-GARCH(1,1)-in-mean model are visibly closer to 1 (perfect correlation) after the inauguration of the cable (marked with a circle in the plot) than before, when they fluctuated wildly. Expectedly, no similar the effect is detected when observing the Sardinia-North correlations (Figure 1, lower panel). Correlations remain volatile and well below 1 on average even after the cable.

5. Conclusion

In this paper, we have explored volatility transmission patterns among zonal electricity prices before and after the inauguration of a new interconnection line linking Sardinia, an island rich in intermittent renewables, with two neighbouring zones. The results of estimating a VAR-GARCH-in-mean model show that the SAPEI cable allowed for stronger volatility transmission from Sardinia, and that such volatility is associated with lower average zonal prices in the neighbouring zones. The conditional correlations between Sardinia and South prices, based on the model estimates, converge to unity after opening the SAPEI cable.

These results are consistent with a theoretical depiction of the electricity market wherein zonal price volatility flows more easily from a net importer (such as Sardinia) to its neighbouring zones, than from a net exporting zone (e.g. the South zone in Italy). One reason may be that renewables, while causing volatility, can also alleviate congestion if they perform an import substitution function (see also Sapio 2015, Boffa and Sapio 2015). The declining trend in power demand and the burgeoning renewables in Sardinia, while worrisome for their volatility implications, have in fact eased the outflow of volatility from the island.

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Appendix: Tables and Plots

Conditional Mean Equation								
North			Sardinia			South		
	Coeff.	*p*-value		Coeff.	*p*-value		Coeff.	*p*-value
β_n	0.473	0	β_{ni}	0.428	0	β_{ns}	0.284	0
			β^*_{ni}	0.036	0.030	β^*_{ns}	-0.297	0
β_{in}	0.186	0	β_i	-0.008	0.640	β_{is}	0.054	0
β^*_{in}	-0.171	0				β^*_{is}	-0.030	0
β_{sn}	0.273	0	β_{si}	0.559	0	β_s	0.435	0
β^*_{sn}	-0.303	0	β^*_{si}	-0.541	0			
			θ_{ni}	-0.134	0.004	θ_{ns}	0.177	0
			θ^*_{ni}	-0.140	0.003	θ^*_{ns}	0.114	0
θ_{in}	-0.016	0.087				θ_{is}	0.394	0
θ^*_{in}	-0.027	0.003				θ^*_{is}	-0.459	0
θ_{sn}	-0.563	0	θ_{si}	-0.999	0			
θ^*_{sn}	0.623	0	θ^*_{si}	0.782	0			
α_n	0.002	0.784	α_i	0.063	0	α_s	-0.013	0.032
w_n	0.003	0.548	w_i	0.006	0.317	w_s	-0.006	0.282
$\beta_{7,n}$	0.170	0	$\beta_{7,i}$	0.171	0	$\beta_{7,s}$	0.159	0
$\delta_{oil,n}$	0.008	0.819	$\delta_{oil,i}$	-0.050	0.191	$\delta_{oil,s}$	-0.063	0.142
$\delta_{gas,n}$	0.104	0	$\delta_{gas,i}$	0.080	0	$\delta_{gas,s}$	0.092	0

Table 1: Estimates of the VAR-GARCH-in-mean model: conditional mean equation, autoregressive and control coefficients. Note: Standard errors (S.E.) are calculated using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. The effect of the 2011 new cable introduction is measured by parameters with *.

Conditional Variance Equation								
North			Sardinia			South		
	Coeff.	*p*-value		Coeff.	*p*-value		Coeff.	*p*-value
a_n	0.975	0	a_{ni}	-0.005	0.414	a_{ns}	0.025	0.009
			a^*_{ni}	0.015	0.031	a^*_{ns}	-0.023	0.005
a_{in}	0.006	0.751	a_i	0.733	0	a_{is}	0.244	0
a^*_{in}	0.041	0.065				a^*_{is}	-0.033	0.156
a_{sn}	0.031	0	a_{si}	0.022	0.010	a_s	0.948	0
a^*_{sn}	-0.005	0.565	a^*_{si}	-0.001	0.867			
g_n	0.150	0	g_{ni}	-0.031	0.114	g_{ns}	-0.141	0
			g^*_{ni}	0.105	0	g^*_{ns}	0.044	0.253
g_{in}	0.569	0	g_i	-1.108	0	g_{is}	0.433	0.001
g^*_{in}	-0.674	0				g^*_{is}	0.995	0
g_{sn}	-0.141	0	g_{si}	0.046	0.126	g_s	0.136	0.001
g^*_{sn}	0.019	0.606	g^*_{si}	0.065	0			

Table 2: Estimates of the VAR-GARCH-in-mean model: conditional variance equation, A matrix (ARCH effects) and G matrix (GARCH effects). The covariance stationarity condition is satisfied by all the estimated models, all the eigenvalues of A' A + G' G being less than one in modulus. Note that in the conditional variance equation the signs of the parameters are not relevant.

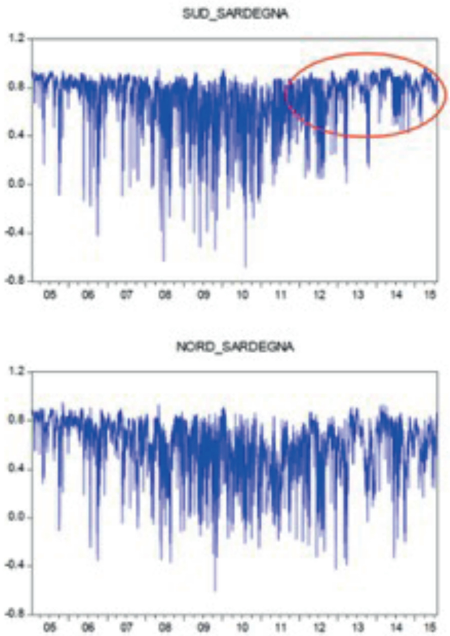

Figure 1. Conditional correlations between Sardinia and South log-prices (upper panel) and between Sardinia and North log-prices (lower panel) between 2005 and 2015, as estimated through the VAR-GARCH-in-mean model. The red circle highlights the post-cable correlations.

Performance analysis and experimental validation of a solar-assisted heat pump fed by photovoltaic-thermal collectors

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Abstract

Solar energy can clearly help to meet the energy requirements of heating and cooling in industry and households. Their widespread use depends on the development of cost-effective and high-efficient systems. The join installation of heat pumps and photovoltaics/thermal (PVT) can greatly contribute to these targets, since the solar energy can provide a heat source at a higher temperature level than atmospheric conditions in winter season. The coefficient of performance (COP) of a heat pump therefore increases and the temperature of the collector is reduced, so the heat loss from the collector to the surroundings decreases, resulting in higher collector efficiencies.

This paper shows the simulation of such a system, performed in trnsys and its experimental validation. From the collecting operating parameters and the actual design of the system, the final objective of the work is to analyze the most appropriate size of the storage (water tanks) for optimizing the efficiency of the system. Results show that the working cold temperature ranges from 10 to 20 ºC and the seasonal COP is raised up to 4.62, instead of 2.96 when working between 7 and 10 ºC. If photovoltaic self-consumption is taken into account, the COP of the machine that is achieved by combining it with the hybrid panels is 7.43 since the electricity consumption of the grid is reduced.

1. Introduction

Final energy consumption in EU-28 rose up 1084 Mtoe in 2015 (Eurostat, 2017), showing three dominant categories: transport (33.1%), households (25.4%) and industry (25.3%). In EU households, heating and hot water alone account for 79% of total final energy use (192.5 Mtoe). In industry, 70.6% of energy consumption (193.6 Mtoe) was used for space and industrial process heating. These figures clearly indicate the huge potential of acting on heating processes both in industry and households sectors: heating and cooling consume half of the EU's energy and it is know that much of it is wasted (EU, 2016).

Currently, only 16% of heating and cooling is generated from renewable energy. The remaining 84% is still generated from fossil fuels. The fulfillment of the EU’s climate and energy goals requires these sectors to sharply reduce its energy consumption and to cut its use of fossil fuels. Heat pumps (HP) present qualified properties to have a significant contribution in this effort. The more efficient a heat pump is the more cost-effective and less energy consuming it will be to operate.

Combination of solar thermal collectors and heat pump in a single solar assisted heat pump (SAHP) system has been widely used for various purposes including water heating. There exists a growing interest towards most effective use of solar heat pump systems for residential use, as indicated by the International Energy Agency through the Task44 of the Solar Heating and Cooling (SHC) Programme.

The Task aimed at optimizing combinations of solar thermal energy and heat pump, primarily for one family houses (IEA, 2013). That is, one of the items in focus were small-scale residential heating and hot water systems that use heat pumps and any type of solar thermal collectors as the main components.

During the last decade, there have been numerous contributions regarding SAHP systems for low temperature applications. Bukert (2016) carried out a complete and systematic review. Most of the literature refers to conventional solar collectors (Wang et al, 2017; Bellos and Tzivanidis, 2017), although also the solar hybrid PVT panels are being considered (Bertram et al, 2012; Kim et al, 2014; Antoñanzas et al, 2015; Buker and Riffat, 2016; Del Amo et. Al, 2017). They present important advantages such as the room saving on the roof and the efficiency.

2. Methodology

The combination of PVT with a SAHP is very convenient attending to the optimum operation conditions of both systems. The performance of the PVT collectors is better as lower is it working temperature: thermal efficiency is higher in those conditions because the convection losses are considerably lower; and at the same time the electrical efficiency is also higher because of the cells refrigeration. On the contrary, when the heat pump is operating in heating mode, its behavior improves with high temperature because the higher temperature of the cold focus diminishes the compressor consumption.

There exists therefore an optimum operation point in the coupling. Such point is not easy to determine since it requires an annual simulation to analyze the temperature of the three-way valve that maximizes production. This study requires a dynamic simulation to check the variation on that temperature along the different periods of the year.

The model was elaborated in Trnsys, a flexible graphically based software environment used to simulate the behavior of transient systems. The three main components of the installation (PVT panels, heat pump and storages) where introduced, as well as all the additional required components, both in the hydraulic and the electrical circuits. One the initial design conditions were tested, different operation conditions were simulated. Firstly, by introducing the weather conditions along the year, the very different operation conditions were considered in order to determine the optimum operation temperature for the panels at each stage. Secondly, variations on the sizes of both in the cold and hot deposits, lead to carefully analyze the better relations among the solar surface, the SAHP power and the capacity of the storages.

3. Case study

A real system of PVT+SAHP is considered in this paper. It is operating on the roof of an industry in Zaragoza (Spain). The installation consists of 25 hybrid panels (η_o = 0,507, a_1 = 4,95 W/m^{2}K, a_2 = 0,021 W/m^{2}K^2), a water-water heat pump of 20 kW and two storage units (one for the cold focus and another one for the hot one), each of 2000 liters. Each reservoir is composed of two 1000 l deposits connected in series to favor stratification.

Figure 1 represents the hydraulic scheme of the considered installation. The primary circuit has an air heatsink that protects of over temperature and allows performing maintenance tasks avoiding an excess temperature in the panels. The primary circuit is driven by a variable flow pump. The heat of the panels is introduced into the two reservoirs of the cold focus.

As the inlet temperature varies throughout the day depending on the available irradiance, a three-way valve (diverter) is installed allowing the high temperature heat flow to be directed to the upper tank and the low temperature heat flow in the lower tank. In this way, the heat of the beginning and end of the day can be used even if the upper tank is hot, without eliminating the stratification reached during the day.

The heat pump extracts the heat from the cold focus at low temperature (10-30 ºC) and gives it to the high temperature (55-65 ºC) hot tanks. For this purpose this heat pump consumes electricity from the electrical circuit where part is supplied by the panels and part comes from the public network. The sizing of the installation has to be aware about defining the cold tanks volume to be heated along the day.

A three-way valve is required between the cold storage and the heat pump tanks, so that the system can operate. This type of heat pump presents a defined working range (5-27^{0}C) and the machine stops when is operated out it. The temperature of the cold side can rise at specific moments (maintenance, low consumption …); then, the temperature will be exceeded and the SAHP could not be started again until the tanks cooled. To avoid such situation, the three-way valve allows working at the desired temperature.

The adjustment of this three-way valve is the key issue of the problem, in order to maximize the production of the installation. This is where the interest lies because a common point has to be determined between the panels (which work better at the lowest temperature) and the heat pump (which demands higher temperature to operate with higher COP, and consequently with lower consumption). In the discharge circuit three circuits are available for consumption: air heater, domestic hot water (DHW) consumption and heating. At the moment of the data collection, only the air heater has been used to simulate the heat demand.

The electrical circuit has been connected in a self-consumption regime with zero injection to the network due to the current regulation in Spain. The electrical production of the PVTs is connected in the general part of the electrical panel. This production can be consumed by any equipment of any of the electrical circuits of the industrial building. As estimation, this work will compare production and consumption to analyze the percentage of self-consumption of the facility.

Figure 1. Hydraulic scheme of the installation

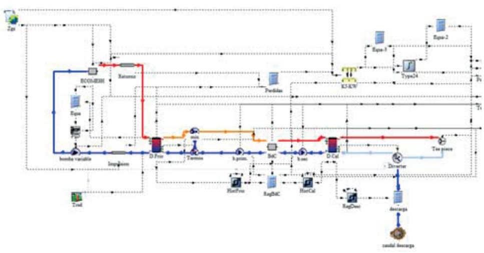

Figure 2. Trnsys simulation scheme

4. Simulation and validation

The model of the facility simulated in Trnsys is shown in Figure 2. Main input data are meteorological registers of Zaragoza and thermal and electrical demands of the industrial facility, in addition to the features of the different elements composing the system.

The simulation shows that the system is quite stable during the summer months. In the upper zone of the graph (Figure 3), the temperature profile of the hot tanks can be observed. It oscillates between 25 to 50 ºC each day. In the lower zone, the temperature profile of the primary circuit is represented, in a range of 10-20 ºC. That is, during the summer period, provided that the consumption is sufficient, the temperature working range of the panels is very low compared to their usual operating range in conventional DHW installations.

For illustrating the situation during the winter period, the temperature profile between the hours 0 and 500 of the year is represented (Figure 4). The results show that the minimum demanded temperature is not reached due to the lack of irradiation. The solar catchment does not sufficiently heat the cold storage tank and as soon as it is heated, the SAHP cools it rapidly by heating the hot tanks.

As the irradiation is lower in winter, the heating obtained in the warm side is lower. Consequently, the SAHP needs to be combined with an additional cold body or to be supported by an auxiliary system in order to get the fixed consumption consigned temperature.

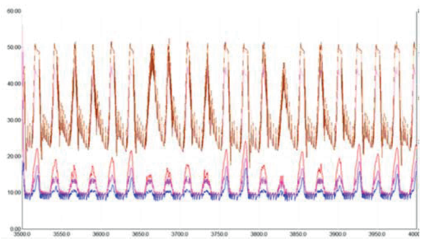

Figure 3. Temperature profile of the collectors, cold medium and hot medium of the installation between hours 3500 and 4000 of the year (summer period).

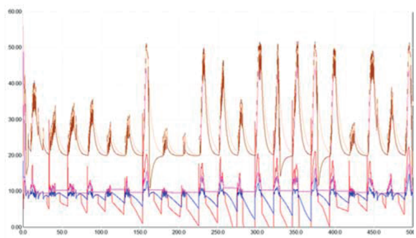

Figure 4. Temperature profile of the collectors, cold medium and hot medium of the installation between hours 0 and 500 of the year (winter period).

The three-way valve controlling the inlet temperature to the SAHP is not activated because the tank is under the 27 ^{0}C to which it is tared. Establishing the set point temperature in 27ºC prevents the SAHP from being stopped by over temperature on the cold side.

For carrying out the validation of the Trnsys model, obtained results and experimental measurements are compared for a day with similar meteorological parameters. Figure 5 and Figure 6 represent the simulated and registered data a specific day in May. It can be appreciated a significant coincidence on the results, so the model is accurate.

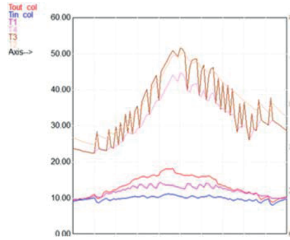

Figure 5. Trnsys simulation for a reference day

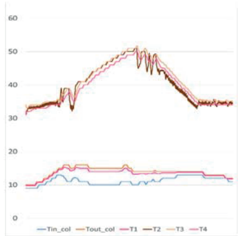

Figure 6. Registered data 05/08/2017

	Simulation	Monitoring	Diff. (%)
Irradiación horizontal (kWh/m2.día)	7.5	7.7	2.67%
Solar Thermal production (kWh/día)	337	322.8	-4.21%
Photovoltaics production (kWh/día)	69	66.5	-3.62%
HP contribution to thermal consumption (kWh/día)	494	485	-1.82%
Electric consumption of the HP (kWh/día)	152	161.7	6.36%

Table 1. Simulation vs experimental results

5. Results

The dynamic analysis is performed in a minutely basis and results are summarized in the Table 2. It shows the available irradiation (horizontal and on a tilted surface) at the installation location, as well as the thermal and electrical production of the panels, the thermal production and electrical consumption of the heat pump. Additionally, the seasonal COP, percentages of self-consumption and savings, and finally the electricity discharged to the grid are also provided. The PV production consumed by the HP is 67.6%. It represents 37.8% of the total demand of the HP, so the remaining 62.2% comes from the network. The PV production is sometimes greater than the consumption of the pump and is poured into the grid, which in this case is self-consumed by other consumptions of the facility.

	Irradiation		PVT panels		Heat Pump					
	Irradiation horizontal (kWh/m².year)	Irradiation panel (kWh/m².year)	PV_PVT (kWh/year)	Q_PVT (kWh/year)	HP_Thermal Production (kWh/year)	HP_Electrical consumption (kWh/year)	COP	PV self-consum.	PV savings in HP	PV to grid (kWh/year)
Jan.	49	78	397	1.950	2.754	551	5,00	55,7%	40,2%	176
Feb.	67	96	486	2.496	3.405	718	4,74	66,6%	45,1%	162
Mar.	117	147	730	3.867	5.324	1.193	4,46	73,3%	44,8%	195
Apr.	136	138	670	3.836	5.162	1.096	4,71	63,7%	38,9%	243
May	175	160	767	4.731	6.375	1.367	4,66	66,1%	37,1%	260
Jun.	192	166	792	5.169	6.965	1.526	4,57	72,8%	37,8%	215
Jul.	201	179	855	5.864	7.977	1.795	4,44	72,7%	34,6%	233
Aug.	178	176	857	5.745	7.897	1.797	4,39	75,1%	35,8%	214
Sep.	136	155	769	4.984	6.852	1.523	4,50	72,2%	36,5%	213
Oct.	91	124	623	3.856	5.319	1.142	4,66	67,1%	36,6%	205
Nov.	54	80	402	2.258	3.104	591	5,25	51,8%	35,3%	194
Dec.	42	70	353	1.791	2.482	471	5,26	47,4%	35,5%	186
year	1.439	1.568	7.701	46.548	63.615	13.771	4,62	67,60%	37,80%	2.495

Table 2. Monthly and yearly energy balance of the PVT+SAHP system

	Irradiation		PVT panels		Heat Pump					
	Irr_hor (kWh/m².year)	Irr_panel (kWh/m².year)	PV_PVT (kWh/year)	Q_PVT (kWh/año)	HP_Thermal Production (kWh/year)	HP_Electrical consumption (kWh/year)	COP	PV self-consum.	PV savings in HP	PV to grid (kWh/year)
Jan.	49	78	793	3.607	5.100	1.270	4,02	73,0%	45,6%	214
Feb.	67	96	972	4.534	6.330	1.692	3,74	78,7%	45,2%	207
Mar.	117	147	1458	7.008	10.029	2.846	3,52	83,2%	42,6%	244
Apr.	136	138	1338	6.960	9.836	2.650	3,71	84,3%	42,6%	210
May	175	160	1533	8.517	12.143	3.387	3,59	88,8%	40,2%	172
Jun.	192	166	1582	9.160	13.279	3.902	3,40	90,5%	36,7%	150
Jul.	201	179	1708	10.397	15.220	4.562	3,34	92,2%	34,5%	133
Aug.	178	176	1711	10.202	15.046	4.495	3,35	92,6%	35,3%	127
Sep.	136	155	1535	8.902	13.056	3.763	3,47	90,7%	37,0%	144
Oct.	91	124	1245	6.941	9.882	2.669	3,70	84,9%	39,6%	188
Nov.	54	80	804	4.112	5.719	1.418	4,03	74,4%	42,2%	206
Dec.	42	70	706	3.317	4.467	1.068	4,18	69,5%	45,9%	216
year	1.439	1.568	15386	83.656	120.106	33.722	3,56	85,60%	39,06%	2.216

Table 3. Monthly and yearly energy balance of the optimized PVT+SAHP system

The working temperature range of the cold spot in the installation ranges from 10 to 20 ºC. As a consequence, the seasonal COP (SPF) achieved in the heat pump by increasing the working temperature of the cold spot is 4.62, instead of 2.96 when working between 7 and 10 ºC. If photovoltaic self-consumption is taken into account, the COP of the machine that is achieved by combining it with the hybrid panels is 7.43 since the electricity consumption of the grid is reduced.

From the results it is also derived that thermal and photovoltaic productions are higher than if the panels themselves directly heated the water to the consumption temperature. In this case, the thermal output of each panel per year is 1861.9 kWh, compared to 1415.1 kWh that would generate in the same installation without HP. This represents an increase of 24% in thermal production. The same happens in the photovoltaic production: 308 kWh/panel·year with HP and 269.5 kWh/panel·year when working directly for heating of ACS, which supposes an increase of 12.5% in photovoltaic production.

In this installation there are four fundamental sizing variables in the installation: the solar surface (S_{col}), the cold accumulation volume (V_c), the machine's power (P_{HP}) and the volume of hot accumulation volume (V_H). These four parameters need to be correctly dimensioned to obtain a balance in the installation that maximizes the production according to the energy demand of the consumption.

In this real installation, unfortunately, the solar surface is not enough to feed the HP. As shown in the simulation, the HP has numerous shutdowns because the collecting surface is not sufficient to heat V_C, and as a consequence it does not take out all the production it would allow. In order for this machine to produce as much energy as possible, a larger S_{col} and a higher V_C are needed. In order to achieve the greatest number of working hours of the machine, a parametric analysis has been carried out, obtaining the relation of dimensions for those relevant variables. The ratios that optimize operation (considering at this stage nor the economic aspects of equipment cost neither energy cost of the energy saved) are, per installed kWt of the HP: related to the receptor 1.7 panels/kW_t (or 2.8 m^2/kWt); and regarding the cold and warm water storage 206 l/kW_t and 35 l/kW_t, respectively. By introducing this optimized size on the simulation, results given in Table 3.

6. Conclusions

A complete model to simulate SAHP with PVT panels has been developed and validated with real data registered in the facility. Results are well accurate and the simulation can be used, in a first step, to optimize the basic parameters of the sizing and to obtain significant ratios. Secondly, it constitutes a powerful tool for the industry developing and selling the equipment, as well as to the research on the energy efficiency and renewable energies integration field.

The studied facility, designed to only work in heat mode, is not well-sized and presents a lack of solar catchment. For correctly feeding the 29 KW_t HP, around 50 panels (instead of 25), and 6 m^3 of V_c (instead of 2 m^3) would be required. In its current state, there exist two alternative operation objectives: just being a pre-heating for an additional existing heating equipment (boilers for example) or installing a parallel circuit so that when the solar contribution is not able to supply enough heat, another system (eg. geothermal) cold support the demands.

The further activities to be developed on the facility should include seasonal storage to take advantage of the heat flow receiving in summer periods, when the production exceeds the existing demands.

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Energy efficiency and stakeholders: Barriers, costs and benefits of implementation. The Naples case study in the EUFORIE Project.

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Abstract

IEA estimates that energy efficiency may account for as much as 70% of the reduction in global energy demand, assuming that nations keep recent commitments to energy efficiency policies (IEA 2012). Energy efficiency advocates also argue that efficiency improvements can provide social benefits such as increased productivity and employment. For this reason, it is important to engage all the stakeholders and make them the main actors of these policies and plans. In this study, we asked to a selected group of stakeholders to address problems about energy efficiency implementation and to tell their level of engagement on these policies.

1.1. Introduction

The most important reason to recommend energy efficiency is that it has the greatest potential to limit future energy demand and face energy shortages. The International Energy Association (IEA) estimates that the global demand for energy may increase by 35% by the year 2035 (IEA, 2012). However, worldwide economies are not fully exploiting the potential of energy efficiency activities to save energy for the future generations (IDFC – 2014). IEA estimates that energy efficiency may account for as much as 70% of the reduction in global energy demand, assuming that nations keep recent commitments to energy efficiency policies (IEA 2012). The project European Futures of Energy Efficiency (EUFORIE) is a target-oriented project aiming at providing multiple results and impacts supporting sustainable development and competitiveness. The project EUFORIE is based on a multi-scale analysis and participatory approach. It is designed according to the European Union´s political targets 20-20-20, Europe's Energy Efficiency Plan and Energy Efficiency Directive (2012/27/EU)), and the goals of the Horizon 2020 R&D program. Most Governments have implemented a wide range of policies and plans to accelerate the development and adoption of energy efficiency measures. Energy efficiency advocates also argue that efficiency improvements can provide social benefits such as increased productivity and employment, reductions in the high-energy cost burden faced by low-income households, improved comfort and public health, enhanced national security, and conservation of finite resources such as oil and natural gas (Romm 1999; Jochem 2000; Geller 2003). For this reason, it is important to engage all the stakeholders and make them the main actors of these policies and plans. Many countries use a strategy development or action planning process as a means to engage stakeholders, build consensus and activate action on energy efficiency. These strategies and action plans help guide and encourage energy efficiency policy development and implementation by: *placing energy efficiency policy within the broader policy context; allocating resources across the range of possible energy efficiency policies; capturing synergies between policies; engaging stakeholders and building political consensus; and assigning responsibility for policy development, implementation and oversight* (IEA, 2009b). National energy efficiency strategies play an important role as they provide a high-level overview of how a country can meet economy-wide goals. The European Union's 20-20-20 target aims for a 20% reduction in primary energy use compared with projected levels by 2020. An energy efficiency strategy should also be comprehensive in describing the approach to and rationale for energy efficiency policies and plans.

1.2. Survey through questionnaires

We used questionnaires as a major tool to investigate stakeholders' opinions and allow them to express their feelings about policies and barriers they face in daily activities on the topic. An energy-efficiency oriented questionnaire was sent to a group of around 200 selected stakeholders from October 2016 and the consultation was stopped at the end of the year. We received 83 replies, i.e. 41.5% of replies. The aim of this consultation was to understand the level of engagement of stakeholders on energy efficiency and their knowledge about this issue.

The questionnaire was composed by 29 questions, some of which general questions about energy efficiency and stakeholder's behavior and some more technical, linked to the EUFORIE project. The first set of questions were meant to investigate what stakeholders think about energy efficiency and what they know about it. In the second part, we also tried to assess their present engagement or how they could be engaged in the future. Questionnaires were proposed by means of personal interviews, contacts during specialized meetings and online compilation. In several questions respondents were asked to mark more than one answer. For this reason, the total percentages most often overcome 100%. Results will, however, still be expressed as %, because this allows at least a comparison among the answers related to each individual question. The total set of questions is listed in the survey at the following link as indicated in the footnote[1].

Figure 1.1 deals with the definition of the energy efficiency concept. Many respondents (83,30%) show a lifestyle-oriented definition of the concept, aiming at consuming less and spending less, without decreasing the quality of life. This points out what is the most important result to be achieved, namely providing technologies and organization forms that do not affect the present living standard. Very likely policies that force lifestyles to decrease would not meet stakeholders' acceptance. The need for additional information about energy efficiency seems a crucial issue also in the minds of stakeholders. For this to be achieved, they identify the need to spread the concept via media (66.7%), schools (55.6%), public offices (55.6%) that act as contacts for stakeholders, promotion activities. This would certainly require a planned strategy by policy-makers and an investment of resources. Surprisingly, self-managed tools such as "social networks" are not considered a potential solution, very likely due to the need for expert advice, that stakeholders attribute to Institutional planning and intervention. Stakeholders think that it is important to inform more people, via media (66,70%) or schools (55,60%), or to open some offices in charge to inform about the existing energy efficiency solutions (55,60%) or to promote the concept through events, contests or other ways (55,60%).

In fact, lack of information was identified as the main barrier to the implementation of energy efficiency by all respondents, together with insufficient action by public administration: the latter is considered the second most important barrier (62%), followed by some confusion between energy efficiency and renewable energy (39%), lack of financing tools (14%), and lastly the idea that in Italy we have other more urgent needs to take care of, instead of talking about energy efficiency (12%). Surprisingly, stakeholders attribute a small importance to the technical aspects (considered not to be a barrier) and the financial aspects (likely the existing incentives are considered sufficiently attractive). The possibility to save money is not the only solution that governments should consider reducing consumption. Result shows that 72% of respondents think that incentives are not the only

[1] https://docs.google.com/forms/d/1XsZV0i4duWNJPTuiJ4saYjaeaQs4Ne-SfrND5Gqp6ww/edit?c=0&w=1

way, although all of them agree that they are a good starting point to support effective changes in stakeholders' behaviors.

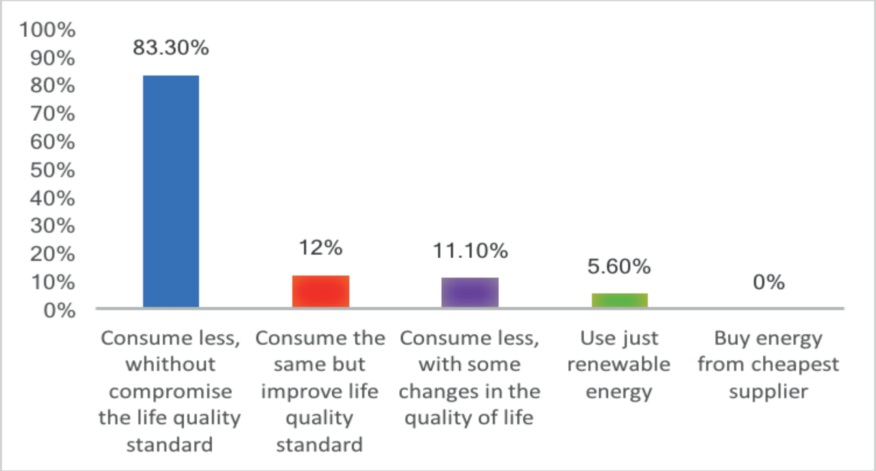

Figure 1.1 – What does Energy Efficiency mean?

Concerning stakeholders' awareness about Italian subsidies and regulations regarding the energy efficiency matter, Figure 1.3 points out that the 55.6% of respondents declare to be aware of the financial aids provided by the Italian government, and the 44,4% of stakeholders think they only know a part of them, in this case respondents could trace one answer. Going into further details, we explored to what extent stakeholders were informed of some specific incentives.

A question about tax reductions related to actions to improve the efficiency in buildings and houses leads to 88.9% of respondents declaring to be fully informed, while only 11.1% appear not informed, further confirmed by answers to question 3, related to other incentive measures and regulations; then we explore the availability to invest personal funds to improve the energy efficiency of the apartment yielding about 80% of answers in favor of such action, depending on the solutions to be adopted. These results might suggest that people are becoming more aware of energy efficiency options and that they care about the possibility to implement energy saving strategies and tools by using the available tools.

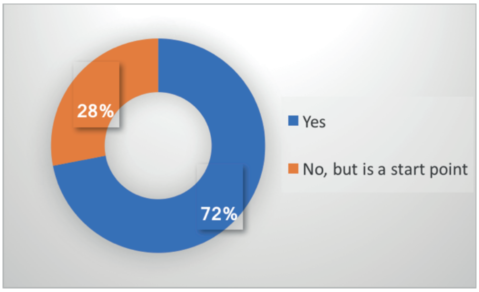

Figure 1.2 – Are subsidies and incentives the only solution to achieve energy efficiency?

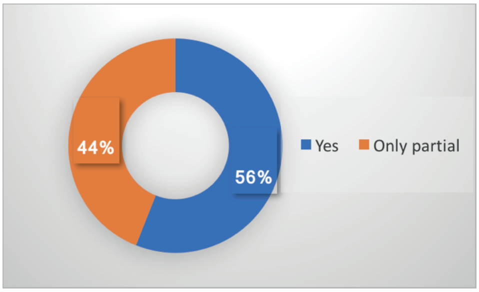

Figure 1.3 – Are you aware of the existence of subsidies and incentives within the Italian regulations?

Stakeholders declared to be well informed when asked about so-called White Certificates (Energy Efficiency Certificates – EEC) - a proof of the energy savings achieved through energy efficiency improvement initiatives and projects -. When asked about ESCo's (Energy Service Companies) the majority said they knew them (83,3%), some of them did not know anything (11,1%), just a few heard about them but did not know any details (5,6%). Such apparent awareness of the existing technical tools for an energy efficiency market is not fully in agreement with the daily experience of ESCo's, as it emerges from our strict collaboration with them (in particular with FEDERESCO, the Italian Federation of ESCo's, http://www.federesco.org/en/). These energy efficiency companies suffer from several regulatory delays and small market acceptance, which calls for increased governmental regulation, promotion and support of the energy efficiency matter, market and actors. Another general question explored how stakeholders were informed about energy efficiency (in order to understand the most effective sources of information). The 61,1% of respondents refer to technical documents for professional reasons: this percentage might depend on the fact that the questionnaire was also sent to experts and people who work in this field or in environmental organizations; social networks and newspaper got the same score, 11,1%, and the answer "other" was indicated by 16,7% of respondents.

After these general questions, additional focus was placed on stakeholders' participation and the possibility to get them involved in some decision-making process. For this reason, the Parthenope team developed (within the EU research projects MARSS - Material Advanced Recovery Sustainable Systems and EUFORIE - European Futures of Energy Efficiency) a roadmap with the main elements, steps and interactions of a decision-making toolkit based on an integrated approach (Figure 1.4).

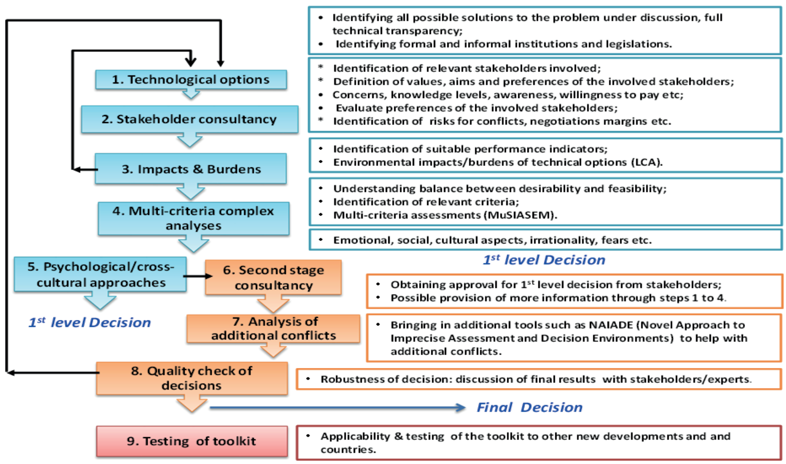

Figure 1.4 – Roadmap

The application of the decision-making roadmap is expected to provide sufficient technical and social evaluation indicators that may allow conflict prevention and final implementation. It seems clear that participatory decision-making approaches need to start from a real demand for specific services and then develop towards the optimum solution (or optimum compromise) through a series of technical details transparently made available, discussed, evaluated across a variety of points of view and finally accepted or rejected.

We made the roadmap scheme available to the interviewed stakeholders and asked them if the roadmap was sufficiently clear and which were the most important steps of the participatory process in their opinion. Stakeholders identified the conflict analysis of the different "stakes" (Step 2) as one of the most important steps for this process (44,4%) and pointed out that in general stakeholders should always be involved (33,3%). Then we kept on asking questions about the engagement of stakeholders in the participatory process, their level and extent of engagement and their availability to get involved in the process personally. Questions 6 and 7 express the stakeholders' trust of the participatory process, pointing out the importance of defining carefully the steps of the participatory process and the interests of the different stakeholders. This is a very important point: if interests and procedures are well defined and transparent, the risk for hidden interests and conflicting decisions is decreased. The largest majority of stakeholders would appreciate being involved in the decision-making process (Table 1.1), and the reason is not, as it might be inferred, that they do not trust policy-makers, but more than that stakeholders think that they may be able to provide points of view and solutions that experts and policy-makers will hardly notice. However, stakeholders identify meetings as the best tool to participate, which is a clear signal of availability to get involved personally in the roadmap and the process. After exploring the issue of roadmap implementation and stakeholders' involvement, we enquired about the possibility to promote this way of taking decision and who should be the principal actors in this process. The answers: the 72,2% of stakeholders said public administration, 50% said all together, each one with his personal capacity, the 38,9% of respondents think the public administration that are in charge of a particular problem, 16,7% technical experts and 5.6% said citizens. The meaning is clear: in spite of claimed lack of trust in administrators, yet stakeholders assign to Institutions and experts the main role to promote a participatory process. This means that institutional roles are not void of importance to the eyes of stakeholders.

After the above questions about participation and stakeholders' engagement, the second part of the questionnaire is more strictly linked to the EUFORIE project. A preliminary survey of what stakeholders consider "energy efficiency" and what are their daily actions provides very telling information. Stakeholders look at a mix of technical solutions (thermal insulation, more efficient appliances) and lifestyle changes (reduction of waste, increased use of public transportation). Their preference to photovoltaic and thermal solar devices is expressed, but correctly the majority of respondents does not consider them as a form of energy efficiency.

As a practical way to address aspects of energy efficiency and be personally involved, Parthenope University invited the local stakeholders in Naples to give rise to the so-called Urban Wellbeing Laboratories, i.e. monthly meetings among environmental associations, professors and researchers, students, professionals and administrators, in order to stress topics of interest for the city separately from the need to take decisions immediately. This kind of preventive action was very well accepted (Table 1.3) and the motivations, once again, were not the lack of reliability of public authorities, but instead the willingness to contribute and the hope to decrease the conflicts (Table 1.4).

Table 1.1 - Stakeholders' Engagement in decision making processes

About roadmap, do you think that participation process could help the harmonization of interests	Yes, but each part of the participatory process must be defined	Maybe, changing some part of the roadmap	Yes	I don't think so

of different stakeholders involved?	43 %	33,3%	16,7%	12 %
Do you think it is important to consult all the stakeholders involved, or just the experts that might help public administration to take decision?	Public administrations have to listen all the stakeholders involved	Just experts must help public administrations	Even if it is complicated, everybody must be involved	
	38,9%	35 %	22,2 %	
Would you like to be involved in decision making related to the problems of your city?	Yes	No, I prefer that just experts think about these problems		
	77,8 %	17 %		
Why would you like to be involved in the problems of your city?	Because to change situations everybody has to give their contribution	Because for some problems we don't need just technological solution	Because I don't trust public administration	
	40%	29 %	26,7 %	
Would you like to participate to meetings on energy efficiency?	Yes	It depends on the meetings	No, I prefer to get informed in other ways	
	77,8 %	17,3 %	7,8%	

Table 1.2 - Concept of Energy Efficiency and daily life habits

Which one of the following options characterizes the concept of energy efficiency in your opinion?	Windows' thermal insulation	Ceiling and walls' thermal insulation	Intensify Public transportation use	Change lifestyle and reduce food waste	Purchase class A + appliances	Solar modules for electricity and water heating
	55,6 %	50 %	44,4 %	38,3 %	27,8%	11,8 %
Which one of the following options do you already adopt in your daily life?	Windows' thermal insulation	Change lifestyle and reduce food waste	Intensify Public transportation use	Purchase class A + appliances	Ceiling and Walls' thermal insulation	Solar modules for electricity and water heating
	50 %	57,3 %	55,4 %	43,8 %	11,1%	9,6 %

Table 1.3 - Urban wellbeing laboratories

Do you think that Wellbeing Laboratories could be useful to discuss the problems of your cities?	Yes	Maybe, but we should do something practical, not just talk about problems	Yes, but University shouldn't be the promoter of the Laboratories
	50%	36%	17,6 %

Table 1.4 - Motivations behind stakeholders' involvement

Do you think that today stakeholders' involvement is more important because public authorities are not reliable?	It is not because they are not reliable, but because every stakeholder has to be involved in public decision making	Stakeholders' involvement reduce conflict and increase social wellness	Others
	50%	41%	11,3 %

After these more general questions, we raised a number of specific, very detailed questions mainly about technical aspects (Tables 1.5 to 1.10). These Tables are very telling concerning specific choices, preferences, knowledge. In each question, we asked to provide a grade from 1 to 10 to the different items, in order to understand how the most important tools and strategies might become more efficient and effective. Questions in Tables 1.5 to 1.10 should be read in the light of previous answers and in the figures. These figures set the stage for understanding the relation between general policy aspects and specific implementation actions. Stakeholders assign higher grades to those actions that they find more useful or where they identify the existence of barriers. Accurate consideration of the entire set of stakeholders' answers and availability to contribute may provide a good starting point to assess future energy efficiency policies. For the sake of clarity and help reading Tables 1.5 to 1.8, we have highlighted in bold the largest percentages of stakeholders for the grades assigned to specific energy efficiency measures, as a proof of consensus in judging that measure. For example, issuing "laws and regulations" was considered a good measure (score: 8) by 30% of responses. Other responses indicated a lower ranking, also characterized by lower consensus. Instead, measures to improve "awareness and behavioral patterns" were judged of intermediate quality and effectiveness (score: 6) by 81% of responses, in so underlining the limited consensus on these measures. We may therefore judge the quality of measures, by cross-checking responses and percentages. Once consensus is monitored, policies may be based on a mix of the most accepted measures, or efforts might be displayed to explain the less accepted measures and try to change the behavior of stakeholders.

Table 1.5 – Main energy efficiency measures implemented in Italy and Europe (Score from 1 to 10, 1 less important – 10 really important)

Grades	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Regulatory Actions: Laws	-	-	-	-	25%	11%	9%	30%	-	-
Reduce Energy Imports	7%	-	-	-	11%	21%	-	22%	-	8%
Increase environmental quality and reduce pollution	-	-	-	-	-	17%	-	83%	-	10%
Reduce Energy Costs	-	5%	-	13%	-	33%	15%	-	-	3%
Energy Service Price	-	-	-	4%	-	18%	72%	-	-	-
Increase the proportion of renewable energy	-	-	8%	-	-	40%	39%	-	-	-
Environmental protection challenges	-	3%	-	2%	11%	5%	21%	-	56%	-
Social and cultural pressure	-	-	-	-	-	-	29%	43%	26%	17%
Awareness and behavioral patterns	-	4%	-	-	-	81%	-	22%	31%	2%
Laws and regulation	-	-	-	-	-	36%	74%	-	-	-
Increase in real estate value	-	-	-	-	-	47%	36%	29%	-	-
Governments' helps to reduce energy consumption	-	-	3%	-	-	-	49%	51%	-	-

Table 1.6 Factors that could help Energy Efficiency Implementation (Score from 1 to 10, 1 less important – 10 really important)

Grades	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Energy Availability	-	-	-	-	-	-	41%	28%	15%	7%
Reduce Energy Importation	4%	3%	-	-	11%	-	31%	36%	41%	6%
Increase environmental quality and reduce pollution	-	-	5%	7%	-	13%	-	63%	-	14%
Reduce Energy Costs	2%	-	-	13%	-	-	-	26%	42%	8%
Energy Service Price	-	-	-	-	3%	-	45%	31%	18%	18%

Increase the proportion of renewable energy	-	-	-	-	-	-	21%	-	33%	-
Environmental protection challenges	-	2%	-	20%	61%	50%	-	-	22%	36%
Social and cultural pressures	-	-	-	-	-	15%	29%	43%	26%	17%
Awareness and behavioral patterns	-	4%	-	-	-	41%	-	62%	-	11%
Laws and regulations	-	5%	-	-	-	-	26%	-	-	-
Increase in real estate value	-	-	-	-	-	-	41%	16%	-	-
Governments' helps to reduce energy consumption	-	-	-	-	-	-	9%	35%	26%	-

Table 1.7 - Energy Efficiency Policies
(Score from 1 to 10, 1 less important – 10 really important)

Grades	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Energetic Audit	-	-	-	-	21%	-	-	33%	-	-
Cost Benefit Analysis for energy system	-	-	-	-	-	41%	-	-	29%	-
Label and energetic certification	-	-	-	-	6%	-	21%	-	-	1%
Information Offices for energy efficiency solutions	-	-	-	-	-	-	51%	-	33%	82%
Subsidy for energy production	-	-	-	-	-	8%	27%	41%	51%	39%

Table 1.8 - Technological Tools for energy efficiency in buildings
(Score from 1 to 10, 1 less important – 10 really important)

Grades	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Smart Thermostat	-	-	-	-	58%	-	32%	-	69%	-
Led Lighting	-	-	-	-	-	-	21%	23%	30%	22%
Energy Management	-	-	-	-	-	16%	11%	45%	22%	-
Energy Start Disposal	-	-	-	-	5%	-	-	40%	37%	-
Electric Charge Station	-	-	9%	-	-	24%	17%	-	-	-
Smart Power Strip	-	-	-	-	61%	45%	59%	26%	-	-

Table 1.9 - Energy efficiency policies in transportation
(Score from 1 to 10, 1 less important – 10 really important)

Grades	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Building regulations	-	-	-	-	-	-	-	36%	-	91%
Information on energy system	-	-	-	-	-	-	33%	55%	-	-
Subsidies on energy efficiency buildings	-	-	-	-	-	13%	-	81%	-	-
Training and networking on industry construction	-	-	-	-	-	39%	4%	25%	2%	-
Promotion of energy services in efficient buildings	-	-	-	-	-	-	9%	43%	56%	8%
Research and development and use of best technologies for building construction	-	-	-	-	-	33%	-	75%	60%	-

Table 1.10 - Energy efficiency policies in buildings
(Score from 1 to 10, 1 less important – 10 really important)

Grades	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Smart Tire	-	-	-	-	-	-	10%	12%	31%	-
Policy on fuel for cars	-	-	-	-	18%	-	70%	63%	80%	-

Policy on fuel for heavy goods vehicles		-	-	-	33%	-	-	71%	69%	-
Eco – driving technologies	-	-	-	-	-	-	49%	56%	82%	-
Best information on vehicles certifications	-	-	-	-	-	13%	-	-	29%	-
Tax subsidies for efficient energy systems		-	-	-	-	57%	23%	11%	36%	-

1.3. Conclusions

A degree of uncertainty and concern remains high among local stakeholders, linked with a lack of awareness and a not always detailed knowledge that stakeholders have on something that takes place close to them. For this reason, it is important to raise the level of attention and awareness on the part of all stakeholders, which, if not well informed, can aggravate their anxiety and their concerns. It is also important to spread information in an adequate way but also bring tools of dissemination and contact, for the different stakeholders that might have divergent needs of information and level of experience and knowledge not similar from other groups of stakeholders involved in a project.

Laboratories seems one of the first steps to build a new relationship and a new way to interact with stakeholders and to receive their help, because sometimes experts and technicians' advices are not enough to address the best solution for a problem. It appears clearly, that in these contests, not because there is a NIMBY attitude, people have a solution that might be better for all the actors involved. Talk with them, find with them a proper alternative to a problem could change the situation and build a new decision-making process, that could mitigate the conflict and reduce the possibility to fight with stakeholders and to implement a project that might have less or no impacts on the territory and on people that live close to some environmental risky project.

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City Building: Concentration of Urban Assets in the Philadelphia Region

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Abstract

Energy is the ultimate driver for urban growth, providing the engine for its physical and economic activities, however it is the concentration of energy into more valuable forms—such as fuels, buildings, institutions, and knowledge—that underlies the capacity for development. The goal of the project was to evaluate the interactions between resources flows (renewable and non-renewable) and the spatial distribution of assets, using household consumption as the primary lens through which to construct a regional e[m]ergy model.

1. Urban Assets

Cities are the great invention of human civilization. They attract people, jobs, and wealth, increasing the collective power of their residents, even as they intensify crime, pollution, or inequality (Bettencourt 2010). Cities have also grown dramatically in population as the amounts of ready power expanded through the modern period, changing their size, shape, and organization, and steadily increasing the proportion of people who live in urban areas, reaching 74% in wealthy countries and 44% in poorer ones. The question this research seeks to answer is how the massive expenditure of power and resources is invested in assets that enhance urban power—from structures and infrastructures to education and information.

Energy is the ultimate driver for urban growth, providing the engine for its physical and economic activities, however it is the concentration of energy into more valuable forms—such as fuels, buildings, institutions, and knowledge—that underlies the capacity for development. The goal of the project was to evaluate the interactions between resources flows (renewable and non-renewable) and the spatial distribution of assets, using household consumption as the primary lens through which to construct a regional e[m]ergy model.

This project was undertaken in support of the development of an agent-based simulation by the Ackoff Collaboratory, which will be used to model the social and economic choices made by the different households (Bharaty 2012). Urban designers have long recognized the value of simulators and games to help evaluate the tradeoffs that city residents and managers must make to improve the sustainability of cities.

There are multiple examples of urban e[m]ergy models by Odum (1995), Brown (1980), Lei (2008), Huang (2001), and Ascione (2004), but we sought a model focused on the consumption decisions by households. Following the insights of Abel (2004) about a socio-economic model of the population, a regional e[m]ergy diagram (Fig. 1.3) is structured around the social, economic, and spatial distribution of people in households as the drivers of consumption in the built environment. Ultimately the choices people make about location and lifestyle drive the patterns of settlement and flows of resources. The work of this project has been two-fold. The first was to develop a sufficiently fine-grained description of the distribution of land uses, buildings, and household types to support the modelling, and second, to understand the accumulation of assets through the region.

1.1 Philadelphia and its region

The city of Philadelphia was founded by William Penn in 1682 at the confluence of the Delaware and Schuylkill rivers. It grew to become the most populous city in the colonies by 1760, then was surpassed by New York in 1800, but remained the second largest until 1900. It is currently the sixth largest city, the seventh largest "metropolitan statistical area (MSA)," and the eight largest "combined statistical area (CSA)" in the United States (US Census 2017). Each of those statistical measures identifies urban boundaries based on degrees of economic and transportation connections, illustrating the point that the boundaries of the city depend on the questions being asked. As part of the ever intensifying "Northeast Megaregion," first identified in the late 1950s (Gottman 1957), Philadelphia has worried about becoming a "sixth borough" of New York since the late nineteenth century (Wes 2015), yet it retains a distinct civic identify and regional accent.

The study area selected for the project is the nine-county region identified by the Delaware Valley Regional Planning Commission (DVRPC), which is a formally constituted entity that administers various state and federal programs. Unlike the MSA, this definition excludes Wilmington, Delaware, because it was formed by the states of Pennsylvania and New Jersey, but accounts for over 95% of the regional population, which is 6,096,905, consisting of 2,346,978 households and 3,189,505 jobs. Over the last decade, DVRPC has developed GIS databases of the region and reporting mechanisms for a regional carbon footprint, which provided the initial data for the project.[1]

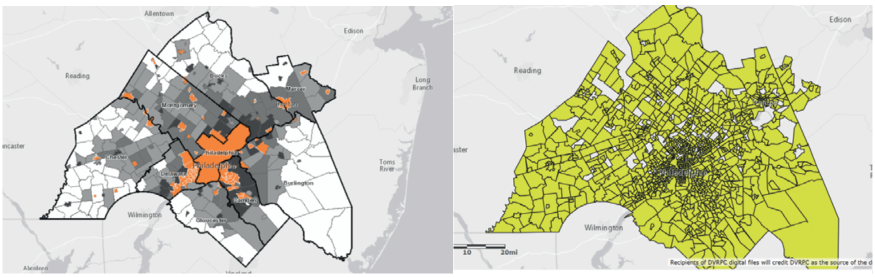

Figure 1.1. Nine county region showing (left) 352 municipalities coded by density and (right) 1,392 census tracts

1.2 Regional data

The land use and building information was extracted and harmonized from county level tax data, the DVRPC GIS land-use models, US Census, and the American Community Survey (ACS).[2] The region has 352 municipalities, including the cities of Philadelphia, Camden, and Trenton (the capital of New Jersey) and 1,379 census tracts, which each represent about 4,000 residents (Fig. 1.1). An overlay of the county-level tax data, the land use map, and the census tract data, was used to

[1] http://www.dvrpc.org/Data/DVRPC/
[2] https://www.census.gov/programs-surveys/acs/

establish the number of residents, workers, and land and building areas by type and use. (Fig. 1.2)

Fig. 1.2. DVRPC Land-use map of center city Philadelphia (left) and detail of census tract 42101000402 in CBD

Building and household consumption data for food, water, and energy were based on national (and regional) norms, while the exchange of resources among sectors has been developed from a variety of sources described in an energy systems diagram of the region. The results are compiled and reported at the level of the census track, giving a detailed picture of the e[m]ergy intensity of land-uses within the region.

Assets were evaluated for each category of land-use in a census tract, from soils and biomass for agriculture and wooded areas to buildings and education levels for households. For the e[m]ergy of building construction, the footprint, floor area, number of stories, and type of use were used to develop assumptions about forms of construction, which were combined with data from RSMeans square foot construction cost to estimate the quantities of different materials in each building (Lee 2017). Values for the value of different educational levels were based on Campbell's evaluation of Minnesota (2009).

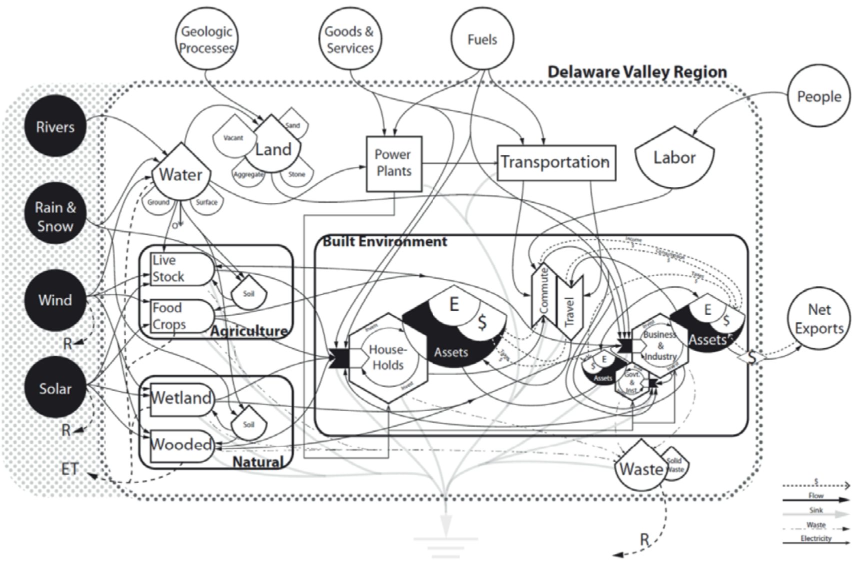

Fig. 1.3. Energy systems diagram of Delaware Valley Region.

Table 1,1: Assets and annual resource flows for five census tracts in Delaware Valley Region

		County / Type			Mercer Cty, NJ	Suburban Community				Philadelphia, PA	CBD Residential				Philadelphia, PA	CBD				Bucks Cty, PA	Rural				Montgomery Cty, PA	Suburban Retail			
		Census Tract #			4,501					1,201					402					104,000					205,807				
						Assets		Flows			Assets		Flows			Assets		Flows			Assets		Flows			Assets		Flows	
Land Use	Type	Item	Unit	nts	Quant.	UEV sej/unit	Emergy sej	UEV sej/unit	Emergy sej/yr	Quant.	UEV sej/unit	Emergy sej	UEV sej/unit	Emergy sej/yr	Quant.	UEV sej/unit	Emergy sej	UEV sej/unit	Emergy sej/yr	Quant.	UEV sej/unit	Emergy sej	UEV sej/unit	Emergy sej/yr	Quant.	UEV sej/unit	Emergy sej	UEV sej/unit	Emergy sej/yr
Agriculture																													
	Assets	Soils	sqm	1	0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			4.47E+07	3.97E+13	1.78E+21			2.36E+04	3.97E+13	9.39E+17		
	Flows	Renewable Inputs	sqm	2	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	4.47E+07			1.23E+09	5.51E+16	2.36E+04			1.23E+09	2.92E+13
		Nonrenewable Inputs	sqm	3	0.00E+00			1.19E+12	0.00E+00	0.00E+00			1.19E+12	0.00E+00	0.00E+00			1.19E+12	0.00E+00	4.47E+07			1.19E+12	5.30E+19	2.36E+04			1.19E+12	2.80E+16
Wetland																													
	Assets	Soils	sqm	1	0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00		
	Flows	Renewable Inputs	sqm	2	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00
Water																													
	Assets	Fresh Water	sqm	4	1.09E+03	1.09E+12	1.19E+15			2.95E+04	1.09E+12	3.21E+16			0.00E+00	1.09E+12	0.00E+00			2.29E+06	1.09E+12	2.50E+18			0.00E+00	1.09E+12	0.00E+00		
	Flows	Renewable Inputs	sqm	2	1.09E+03			1.23E+09	1.35E+12	2.95E+04			1.23E+09	3.63E+13	0.00E+00			1.23E+09	0.00E+00	2.29E+06			1.23E+09	2.82E+15	0.00E+00			1.23E+09	0.00E+00
		River Potential	sqm	4	1.09E+03			6.02E+12	6.58E+15	2.95E+04			6.02E+12	1.77E+17	0.00E+00			6.02E+12	0.00E+00	2.29E+06			6.02E+12	1.38E+19	0.00E+00			6.02E+12	0.00E+00
Wooded																													
	Assets	Forest Biomass	sqm	5	1.04E+04	8.03E+12	8.37E+16			0.00E+00	8.03E+12	0.00E+00			0.00E+00	8.03E+12	0.00E+00			1.91E+07	8.03E+12	1.54E+20			8.20E+04	8.03E+12	6.58E+17		
	Flows	Renewable Inputs	sqm	2	1.04E+04			1.23E+09	1.28E+13	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	1.91E+07			1.23E+09	2.36E+16	8.20E+04			1.23E+09	1.01E+14
		Net Timber Growth	sqm	5	1.04E+04			1.15E+11	1.19E+15	0.00E+00			1.15E+11	0.00E+00	0.00E+00			1.15E+11	0.00E+00	1.91E+07			1.15E+11	2.19E+18	8.20E+04			1.15E+11	9.39E+15
		Timber Harvest	sqm	5	1.04E+04			1.91E+11	1.98E+15	0.00E+00			1.91E+11	0.00E+00	0.00E+00			1.91E+11	0.00E+00	1.91E+07			1.91E+11	3.65E+18	8.20E+04			1.91E+11	1.56E+16
Mining																													
	Assets	Minerals	sqm	6	0.00E+00	1.31E+16	0.00E+00			0.00E+00	1.31E+16	0.00E+00			0.00E+00	1.31E+16	0.00E+00			0.00E+00	1.31E+16	0.00E+00			0.00E+00	1.31E+16	0.00E+00		
	Flows	Renewable Inputs	sqm	2	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00
		Mineral Extraction	sqm	6	0.00E+00			2.62E+15	0.00E+00	0.00E+00			2.62E+15	0.00E+00	0.00E+00			2.62E+15	0.00E+00	0.00E+00			2.62E+15	0.00E+00	0.00E+00			2.62E+15	0.00E+00
Vacant																													
	Assets	Soils	sqm	1	0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			0.00E+00	3.97E+13	0.00E+00			2.45E+04	3.97E+13	9.71E+17		
	Flows	Renewable Inputs	sqm	2	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	0.00E+00			1.23E+09	0.00E+00	2.45E+04			1.23E+09	3.02E+13
Non-Residential																													
	Assets	Land Value asessment	$	7	4.84E+07	1.97E+12	9.53E+19			1.57E+07	1.97E+12	3.08E+19			4.39E+08	1.97E+12	8.66E+20			8.08E+06	1.97E+12	1.59E+19			0.00E+00	1.97E+12	0.00E+00		
		Building Construction	Sej/yr	8	1.19E+19	1.00E+00	1.19E+19			4.29E+18	1.00E+00	4.29E+18			2.27E+20	1.00E+00	2.27E+20			1.65E+19	1.00E+00	1.65E+19			3.48E+18	1.00E+00	3.48E+18		
	Flows	Renewable Inputs	sqm	2	1.02E+06			1.23E+09	1.25E+15	1.16E+05			1.23E+09	1.43E+14	2.76E+05			1.23E+09	3.40E+14	1.86E+06			1.23E+09	2.30E+15	9.52E+05			1.23E+09	1.17E+15
		City Tax property tax	$	9	1.35E+06			1.97E+12	2.66E+18	6.00E+05			1.97E+12	1.18E+18	2.44E+07			1.97E+12	4.80E+19	1.50E+06			1.97E+12	2.96E+18	5.26E+05			1.97E+12	1.04E+18
		Education property tax	$	9	1.40E+06			1.97E+12	2.77E+18	4.93E+05			1.97E+12	9.71E+17	2.00E+07			1.97E+12	3.95E+19	5.22E+06			1.97E+12	1.03E+19	1.91E+06			1.97E+12	3.77E+18
		Labor Wage	$	10	2.42E+08			1.97E+12	4.76E+20	1.84E+07			1.97E+12	3.63E+19	1.37E+09			1.97E+12	2.71E+21	2.68E+07			1.97E+12	5.29E+19	4.49E+07			1.97E+12	8.85E+19
		Water	L/yr	11	2.55E+08			1.55E+09	3.95E+17	1.94E+07			1.55E+09	3.01E+16	1.45E+09			1.55E+09	2.25E+18	2.83E+07			1.55E+09	4.39E+16	4.74E+07			1.55E+09	7.34E+16
		Wastewater	L/yr	12	1.91E+08			3.54E+09	6.77E+17	1.46E+07			3.54E+09	5.16E+16	1.09E+09			3.54E+09	3.85E+18	2.12E+07			3.54E+09	7.51E+16	3.55E+07			3.54E+09	1.26E+17
		Food	Cal	13	3.15E+09			3.99E+09	1.26E+19	2.40E+08			3.99E+09	9.59E+17	1.79E+10			3.99E+09	7.15E+19	3.50E+08			3.99E+09	1.40E+18	5.86E+08			3.99E+09	2.34E+18
		Solid Waste	kg/yr	14	2.00E+06			2.25E+11	4.50E+17	1.53E+05			2.25E+11	3.43E+16	1.14E+07			2.25E+11	2.56E+18	2.22E+05			2.25E+11	5.00E+16	3.72E+05			2.25E+11	8.37E+16
		Non-durable Supplies	$	15	3.63E+06			1.97E+12	7.14E+18	2.77E+05			1.97E+12	5.45E+17	2.06E+07			1.97E+12	4.06E+19	4.03E+05			1.97E+12	7.93E+17	6.74E+05			1.97E+12	1.33E+18
		Electricity 45%	J	16	1.78E+13			2.18E+05	3.89E+18	2.79E+13			2.18E+05	6.09E+18	9.73E+14			2.18E+05	2.12E+20	7.69E+13			2.18E+05	1.68E+19	4.91E+13			2.18E+05	1.07E+19
		Fuel 55%	J	16	2.18E+13			1.41E+05	3.07E+18	3.41E+13			1.41E+05	4.81E+18	1.19E+15			1.41E+05	1.68E+20	9.39E+13			1.41E+05	1.32E+19	6.00E+13			1.41E+05	8.46E+18
		Transp. - commuting	km	17	2.16E+07			varies	3.38E+18	7.79E+07			varies	1.02E+19	3.85E+07			varies	5.31E+18	1.04E+08			varies	1.72E+19	3.17E+07			varies	4.97E+18
Residential																													
	Assets	Land Value asessment	$	7	2.24E+08	1.97E+12	4.41E+20			9.03E+07	1.97E+12	1.78E+20			2.96E+06	1.97E+12	5.84E+18			1.11E+07	1.97E+12	2.20E+19			0.00E+00	1.97E+12	0.00E+00		
		Res - High School & <	people	18	7.30E+01	1.19E+17	8.69E+18			9.80E+01	1.19E+17	1.17E+19			3.82E+02	1.19E+17	4.55E+19			1.73E+03	1.19E+17	2.06E+20			4.17E+02	1.19E+17	4.96E+19		
		Res - College	people	18	2.67E+02	3.56E+17	9.51E+19			1.18E+03	3.56E+17	4.19E+20			1.25E+03	3.56E+17	4.44E+20			2.23E+03	3.56E+17	7.95E+20			8.24E+02	3.56E+17	2.93E+20		
		Res - Grad School & >	people	18	8.01E+02	1.66E+18	1.33E+21			1.96E+03	1.66E+18	3.25E+21			1.26E+03	1.66E+18	2.09E+21			7.12E+02	1.66E+18	1.18E+21			2.22E+02	1.66E+18	3.69E+20		
		Building Construction	Sej/yr	8	1.14E+19	1.00E+00	1.14E+19			1.37E+18	1.00E+00	1.37E+18			3.67E+18	1.00E+00	3.67E+18			1.68E+18	1.00E+00	1.68E+18			5.51E+18	1.00E+00	5.51E+18		
		Automobiles	car	19	9.44E+02	1.01E+15	9.53E+17			1.53E+03	1.01E+15	1.54E+18			1.34E+03	1.01E+15	1.35E+18			5.55E+03	1.01E+15	5.60E+18			1.58E+03	1.01E+15	1.60E+18		
	Flows	Renewable Inputs	sqm	2	6.08E+05			1.23E+09	7.50E+14	2.11E+05			1.23E+09	2.61E+14	2.79E+04			1.23E+09	3.43E+13	1.01E+07			1.23E+09	1.24E+16	5.61E+05			1.23E+09	6.92E+14
		City Tax property tax	$	9	5.01E+06			1.97E+12	9.88E+18	5.00E+06			1.97E+12	9.85E+18	1.08E+05			1.97E+12	2.13E+17	2.26E+06			1.97E+12	4.46E+18	7.08E+05			1.97E+12	1.39E+18
		Education Tax property	$	9	5.22E+06			1.97E+12	1.03E+19	4.11E+06			1.97E+12	8.10E+18	8.89E+04			1.97E+12	1.75E+17	7.87E+06			1.97E+12	1.55E+19	2.57E+06			1.97E+12	5.06E+18
		Household Income	$	10	2.13E+05			1.97E+12	4.20E+17	7.33E+05			1.97E+12	1.44E+18	2.59E+06			1.97E+12	5.10E+18	3.04E+06			1.97E+12	5.99E+18	9.45E+05			1.97E+12	1.86E+18
		Water	L/yr	11	1.69E+08			1.55E+09	2.62E+17	1.09E+08			1.55E+09	1.70E+17	8.36E+07			1.55E+09	1.30E+17	1.87E+08			1.55E+09	2.89E+17	5.21E+07			1.55E+09	8.08E+16
		Wastewater	L/yr	12	1.27E+08			3.54E+09	4.49E+17	8.21E+07			3.54E+09	2.91E+17	6.27E+07			3.54E+09	2.22E+17	1.40E+08			3.54E+09	4.96E+17	3.91E+07			3.54E+09	1.38E+17
		Food	Cal	13	3.77E+09			3.99E+09	1.50E+19	2.44E+09			3.99E+09	9.74E+18	1.87E+09			3.99E+09	7.44E+18	4.17E+09			3.99E+09	1.66E+19	1.16E+09			3.99E+09	4.64E+18
		Solid Waste	kg/yr	14	2.39E+06			2.25E+11	5.38E+17	1.55E+06			2.25E+11	3.49E+17	1.18E+06			2.25E+11	2.67E+17	2.65E+06			2.25E+11	5.95E+17	7.38E+05			2.25E+11	1.66E+17
		Non-durable Supplies	$	15	3.07E+04			1.97E+12	6.04E+16	1.06E+05			1.97E+12	2.08E+17	3.73E+05			1.97E+12	7.35E+17	4.38E+05			1.97E+12	8.62E+17	1.36E+05			1.97E+12	2.68E+17
		Electricity 45%	J	16	5.81E+13			2.18E+05	1.27E+19	6.55E+13			2.18E+05	1.43E+19	2.03E+13			2.18E+05	4.42E+18	9.94E+13			2.18E+05	2.17E+19	3.63E+13			2.18E+05	7.92E+18
		Fuel 55%	J	16	7.10E+13			1.41E+05	1.00E+19	8.01E+13			1.41E+05	1.13E+19	2.48E+13			1.41E+05	3.49E+18	1.21E+14			1.41E+05	1.71E+19	4.44E+13			1.41E+05	6.26E+18
		Transp. non commute	km	17	5.42E+06			varies	8.64E+17	1.34E+07			varies	1.92E+18	7.90E+06			varies	1.11E+18	2.59E+07			varies	4.28E+18	7.83E+06			varies	1.24E+18
Totals		**Land Use**					sej		sej/yr			sej		sej/yr			sej		sej/yr			sej		sej/yr			sej		sej/yr
		Agriculture					0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			1.78E+21		5.30E+19			9.39E+17		2.80E+16
		Wetland					0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00
		Water					1.19E+15		6.58E+15			3.21E+16		1.77E+17			0.00E+00		0.00E+00			2.50E+18		1.38E+19			0.00E+00		0.00E+00
		Wooded					8.37E+16		3.19E+15			0.00E+00		0.00E+00			0.00E+00		0.00E+00			1.54E+20		5.86E+18			6.58E+17		2.51E+16
		Mining					0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00
		Vacant					0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			0.00E+00		0.00E+00			9.71E+17		3.02E+13
		Non-Residential					1.07E+20		5.13E+20			3.51E+19		6.12E+19			1.09E+21		3.30E+21			3.24E+19		1.16E+20			3.48E+18		1.21E+20
		Residential					1.89E+21		6.05E+19			3.86E+21		5.77E+19			2.59E+21		2.33E+19			2.21E+21		8.79E+19			7.19E+20		2.90E+19
		Total					1.99E+21		5.74E+20			3.90E+21		1.19E+20			3.68E+21		3.32E+21			4.18E+21		2.76E+20			7.25E+20		1.50E+20
		Total/sq m					1.17E+15		3.36E+14			1.09E+16		3.32E+14			1.21E+16		1.09E+16			5.16E+13		3.41E+12			4.41E+14		9.15E+13

For the other land uses, such as agriculture, timber, and mining, county or state level data was apportioned to each tract an area basis, which accurately represents the totals, but flattens out the spatial differences. Further work needs to be done with the available spatial data for mining and water resources to reveal any correlation between the distribution of these assets with economic assets. The other asset which needs to be more accurately evaluated are transportation networks.

For the annual energy consumption of buildings the average energy intensity for each class of buildings was obtained from the DOE Building Performance Database and multiplied by the building area. The totals achieved with this bottom-up technique for each county were adjusted to match the top-down consumption totals obtained by DVRPC using aggregate data from energy utilities. Other consumption categories—water, food, waste, and so—were determined with similar methods, compared to county-wide totals when available. In contrast, transportation data is available from a detailed regional survey by DVRPC, which could be assigned to individual census tracts.

The energy systems diagram and model were developed to focus on the consumption level decisions of households, and a basic set of interactions with non-residential activities have been mapped out. Most of these interactions are still aggregated within total consumption, but labor and transportation were both accounted for explicitly.

2. Results

E[m]ergy synthesis were prepared for all 1,379 census tracts in the region, and details of five characteristic tracts are shown in table 1.1 and the spatial intensities charted Figure 2.1. Broadly speaking the results confirm the spatial hierarchy of the city in its region with the central business district (CBD) and CBD Residential exhibiting the greatest e[m]ergy intensity per unit of land. Rural land is lowest, and interestingly the Suburban Community has a greater intensity of assets and annual resource flows than Suburban Retail, reflecting the concentration of residents with higher levels of education and a higher value of household labor.

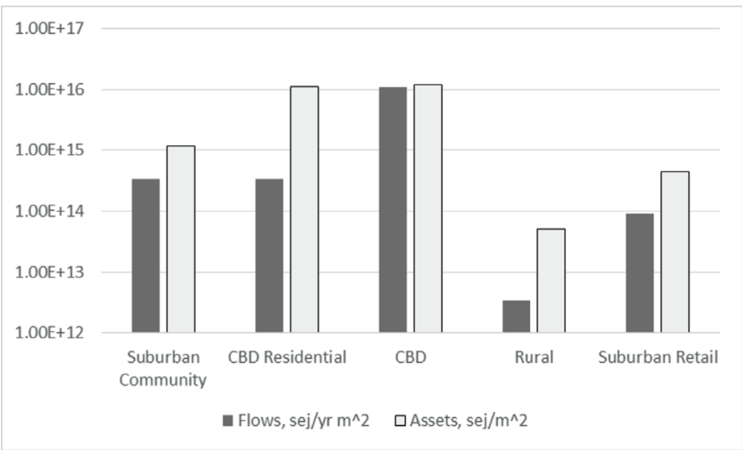

Fig. 2.1. E[m]ergy intensity of assetts and annual flows for 5 census tracts

The same hierarchy is visible when the spatial intensities for all census tracts are plotted in map form in Fig 2.2. The central business district and residential areas form the largest concentrations, but the powerful exurban concentrations are also clearly visible.

The new center-periphery configuration that has emerged over the last 50 years is even more apparent in a mapping of the e[m]ergy per capita plotted in Fig. 2.3.

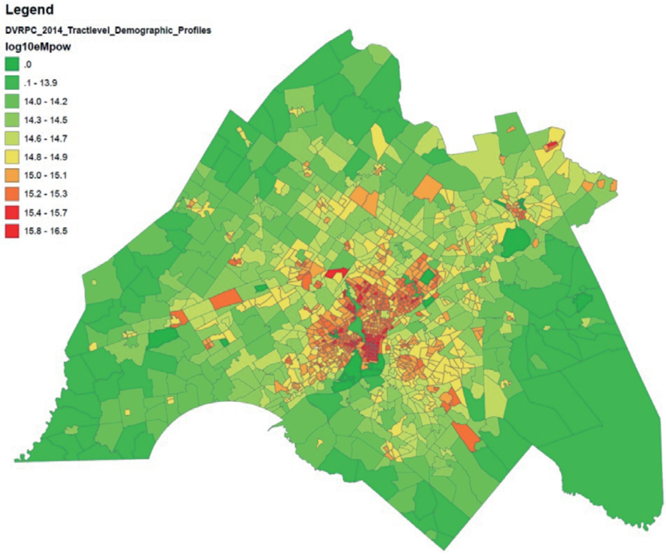

Fig. 2.2. Delaware Valley Region – census tract level: **e[m]ergy intensity per area of land**

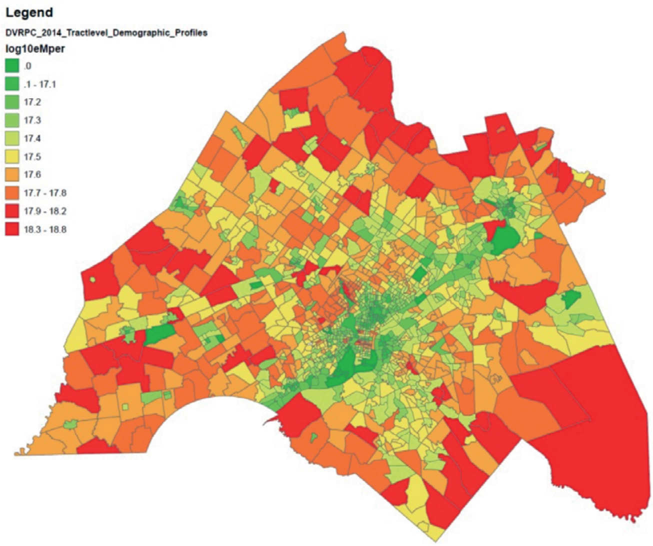

Fig. 2.3. Delaware Valley Region – census tract level: **e[m]ergy intensity per capita**

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Notes Table 1.1

1, DVRPC Land Use, Campbell, 2009. 2, DVRPC Land Use, Chemical value of Rain: 1.05 m/yr, Odum 1996, Campbell 2003a, Campbell 2009. 3, DVRPC Land Use, 2012 Census of Agriculture: total production normalized to agricultural land area, Campbell, 2009. 4, DVRPC Land Use, www.lakepedia.com, USGS National Water Information System 2013, waterdata.usgs.gov, Campbell, 2009. 5, DVRPC Land Use, Forest Service, PA Forests 2009, Campbell, 2009. 6, DVRPC Land Use, USGS Minerals Yearbook, 2010, Campbell, 2009. 7, Property Tax data, NEAD, 2012. 8, Property Tax data, Means SF data, ** RSMeans SQFT Approach. 9, Phila Tax (Property Shark.com), NEAD, 2012. 10, 2012 Economic Census, NEAD, 2012. 11, USGS National Water Information System 2013, Buenfil, 2000. 12, EPA, Numicipal Wastewater, Bjorklund, 2001. 13, USDA, Johansson et al., 2000. 14, EPA, Solid Waste, Brown & Burnakarn, 2003. 15, Bureau of Labor Statistics, NEAD, 2012. 16, DOE Building Performance Database, Brown et al., 2011, Brown & Ulgiati, 2012. 17, DVRPC Transportation Survey, Campbell, 2011. 18, Campbell, 2009. 19, Consumer Reports, 2014.
All transformities have been converted to the new baseline: 1.20E+25 sej.

Reserves at risk: planning with deep uncertainty and high complexity

Umberto Perna

The purpose of the work is to improve value creation for investors of E&P Companies (but applicable to all commodity producers) by estimating more accurately the risk profile of their own developed and undeveloped assets under the exposure to rare, extreme or otherwise "unforeseen" events [1]. The improved understanding of the fragilities hidden within the portfolio derived from achieved through well-known techniques employed outside the industry will lead to improved planning, resource allocation and low-cost implementation into already existing corporate processes.

Method

The measurement of riskiness of reserves is based upon widely adopted methods in Finance to measure exposure to adverse events. By exploiting Extreme Value Theory [2], we assess the Expected Shortfall, over given time horizons in the actualized value of hydrocarbon reserves of a diversified E&P company, subject to varying exposure to movements in the oil price, technical setbacks, and atmospheric events. The model would also allow taking into account other above-surface risk factors like geopolitical events.

Results

Under the analysis performed by the model, the valuation of assets in company portfolio would be generally lower than those presently accounted for. These would however provide to be more consistent during the commodity cycle, allowing for more efficient capital allocation through time and promoting quality-over-quantity of assets and the returns of present and future production. It may reduce the perceived riskiness of the better performing companies as they focus their efforts on the most profitable assets, adsorb and invest capital more efficiently and reduce coordination complexity. Inefficiencies in capital expenditure are computed by taking into account longer development time for new large projects, when the future cash inflows are discounted by more accurate risk measures and the likelihood of delays and cost overruns increases non-linearly with size. The optionality value in contract arrangements regarding the development of reserves can also be derived consequently, allowing for the economic assessment of widely spread PSA arrangements [3] in "abnormal" business times. The analysis is based on plausible synthetic input data, with the model allowing for the assessment of peculiar geological and geographical settings, offering flexibility in the calibration of parameters based on the nature of real-world assets.

Conclusions

The model advances improved measurement of uncertainty and risk of the economic value of assets in the industry by promoting the adoption of more advanced mathematical methods successfully employed in other industries. It recognises the more difficult operating environment with increased volatility in the price of energy commodities and the threat posed by alternative sources of energy. The new approach will avoid the "Overpricing" and "Overbooking" of reserves [4], improving the protection of shareholders and other stakeholders in E&P companies. It can also be extended to comprise cleaner energy investment, shifting focus from a limited resource to plant efficacy and lifetime management. A schematic implementation of the model within established corporate Enterprise Risk Management processes is put forth.

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Candles in the dark: a review of environmental and sustainability indicators and their criticisms.

Abstract: Global attention on sustainability and environmental issues has increased exponentially in the last years. Policy makers always more frequently refer to these concepts as guidelines in their work. But how do we measure sustainability? Until today, and probably for a long time, indicators are the only tool we have available. The scientific community has created many of them: some more practical, to cope with the political necessity of using clear and simple tools, and some more complex, until now mainly used for academic purposes.
In this paper, we review some of the most relevant indicators in the scientific debate of recent years, marking characteristics, boundaries, strengths and critical aspects that have been raised by the community.

Paper Structure:

1. Introduction

1.1 Sustainable development

Sustainable Development (SD) in recent years has been the star guiding, at least in the media, all national and international policies. The concept of SD was inspired by the great ecologists of the twentieth century (Rachel Carson, H. T. Odum, etc.) and has achieved institutional recognition with the book "Limits to Growth" (Meadows et al., 1972) and the UN commissioned report "Our common future" (Bruntland Commission, 1987). According to the latter, SD is "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". In the following decades, a key moment for adopting SD principles at the global level was the Rio de Janeiro Summit (Agenda21, 1992).

SD has been conceived over the years as being made up of three fundamental pillars: environmental, social, and economic. Through these three lenses it should be possible to analyze all the policies and check their impact on sustainability. The threefold basis on which the SD is based represents at the same time its great versatility and comprehensiveness, but also the enormous difficulty of a truly simultaneous, complete and non-fragmented evaluation.

In this paper, we will focus on methods that only - or mainly - consider the environmental-energy aspect of sustainability. The basic idea behind the concept of Environmental Sustainability is the carrying capacity, ie the existence of a finite limit to resource exploitation and waste absorption, beyond which the system is over-exploited and the resulting damage can be serious.

1.2 Indicators

Indicators are tools to quantify certain aspects of reality, eventually bringing different aspects of it to the same unit of measurement. Sustainability indicators (SIs) are an aggregation of simpler indicators, so that they acquire a meaningful significance over the three "filters" of sustainability (economic, social, environmental).
According to (Singh et al., 2008), Sis prepare and assess conditions and trends, provide early warning information to prevent economic, social and environmental damage, help formulate strategies and communicate ideas.

SIs often end up being ‘complex’. The problem of complex indicators is that man is not capable of simultaneously assessing many information. If this operation does not succeed in a single man, approaching complex evaluations is even more difficult in the case of institutions and policy makers, that have a much greater intrinsic inertia. This is one of the reasons why real policies and laws are always based on discrete values, and can’t admit tolerances or uncertainties. Conversely, indicator-makers are aware that the scientific validity of their work can’t withstand excessive simplifications, and has ranges of applicability. The most comprehensive keywords in this perspective are “multi-scale” and “multi-method”, meaning the importance of looking at a particular phenomenon at multiple levels of ‘zoom’ and through as many lenses as possible. This multiplicity of scientific art collides again with the needs of political art, and this intrinsic fight is what makes sustainability science so thought-provoking.

In this paper, we analyze five different approaches to environmental sustainability, together with their main indicators. The methods are Emergy analysis, Extended Exergy analysis, Environmental Footprint, LCA, Planetary Boundaries.

2. Environmental methods and indicators

2.1 Emergy Analysis

Emergy, previously referred to as embodied energy, is the energy of one form (tipically, solar energy calculated in solar embodied joule, seJ) needed to make a product or service, accounted for through direct and indirect transformations. The emergy concept was first created by H. T. Odum, and later developed and implemented by S. Ulgiati and M. Brown (Brown et al., 2016; Brown and Ulgiati, 2004). Today, a large community of scientists use this approach for sustainability assessments worldwide.

Emergy indicators: Emergy Yield Ratio (EYR): The ratio of the emergy yield from a process to the emergy costs. Being constructed as the sum of purchased services and goods plus local ecosystem services, this ratio is always greater than 1 and expresses the economic profitability of an investment, by leveraging on local resources.
Environmental Loading Ratio (ELR): The ratio of nonrenewable and imported emergy use to renewable emergy use. ELR evaluates environmental stress in a production or transformation process. Greater values indicate that the process might be more stressful toward that ecosystem. Emergy Sustainability Index (ESI): The ratio of the Emergy Yield Ratio to the Environmental Loading Ratio, indicates the contribution of a resource or process to the economy per unit of environmental loading.
Empower intensity: The ratio of total emergy use in the economy of a region or nation to the total

area of the region or nation. Fluxes of renewable and nonrenewable emergy can be accounted for as separated, and then divided by the total area considered.

Criticisms: Emergy approach is a supply-side resource quality assessment, that considers value of a resource based on how much biosphere effort (available energy, materials, time) has been invested to produce it. Behind this concept of ‘quality' lies the Maximum Power Principle (Lotka, 1922), that is, the idea that a system optimizes its resources investment in order to ensure survival in evolutionary competition through maximum power output. Systems that develop organization patterns and network links to expand the resource basis and use resources more efficiently are selected against competitors. Such broad natural selection and environmental focus entails that this approach can be considered suitable and valuable in the macro-history of self-organizing ecosystems with very large spatio-temporal boundaries (including cultures and economies), while it may be less functional in comparing more limited and contingent systems.

2.2 Extended Exergy Analysis

Extended Exergy Analysis (EEA) is a method first created by E. Sciubba (Sciubba, 2005). This approach studies systems from a thermodynamic point of view. Exergy is a state function that expresses the amount of work that can be extracted from a system immersed in a reference environment. While the total energy of a process is preserved, a part of exergy is always destroyed, according to the second law of thermodynamics. The EEA seeks to include in this exergetic analysis also the values of labor, capital and environmental costs through their exergetic equivalents.

The main indicator produced by EEA is the extended exergetic cost (EE_c), which is the ratio of the sum of the equivalent exergy inputs needed to produce it, to the extended exergy of the useful output. Its reciprocal is the conversion effectiveness of the system.

Criticisms: the strong, initial assumption of EEA is that the economic system can be thought of as a thermodynamic system, that is, the same thermodynamic laws apply and can describe the functioning of the society. This simplification, similar to that made by emergy analysis, can be considered valid within energy/environmental sustainability, but supporters of complex sustainability consider it to be too reductionist.

2.3 Ecological footprint

The Ecological Footprint’s concept was introduced in the 1990s by William Rees and Mathis Wackernagel (Rees, 1992; Wackernagel and Rees, 1996) In 1990s, William Rees and Mathis Wackernagel introduced the concept of Ecological Footprint (Rees, 1992; Wackernagel and Rees, 1996). Fundamental ideas behind EF are carrying capacity and footprint: EF takes into account the resource consumption and waste assimilation requirements of a defined system (a population, an economic sector, etc.), and translate this value into a footprint, that is the amount of land the analyzed system would need to be sustained, or, which is the same, the ratio of the rate of resource consumption and waste production, to the carrying capacity of that land.

Criticisms: EF has gained enormous popularity since it was developed. Many national states, up to WWF and the United Nations, adopt this method as a sustainability index. Nevertheless, many criticisms have come from academia. Most recent ones were from (Van den Bergh 2014, 2015), (Blomqvist, 2013), (Giampietro and Saltelli, 2014). These critiques range from some method details, to the lack of clear justifications in some inferences and aggregations. In general, the main thread of criticism is the excessive simplification of a "complex" problem such as sustainability, which according to these authors would be impossible to "concentrate" into a single numeric value. If this is intuitively true, we must admit that EF, for its simplicity, has proved to be a very powerful dissemination tool to raise awareness among ordinary people about the issue of environmental sustainability.

2.4 LCA

LifeCycle Assessment is a method to evaluate environmental impacts associated with a product, considering all the stages of its life. Analysis starts from raw material extraction, then passes through materials processing, manufacture, distribution, use, repair and maintenance, disposal or recycling. LCA si compone di 4 fasi principali: 1) definition of goals (which includes establishing the functional unit, system boundaries, impact categories); 2) inventory analysis; 3) impact assessment; 4) interpretation. This structure is fundamental because it guarantees, together with other ISO 14000 requirements, a standardized procedure to follow, and a certain reliability of the results. This common frame also allowed the method to get a broad diffusion at the industrial level.

Some of the main, most common indicators of LCA are: Global warming potential, stratospheric ozone depletion, acidification, eutrophication, human toxicity, eco-toxicity.

Criticisms: LCA, being a standardized procedure, ensures a certain replicability of studies. Nonetheless, there is always the risk linked to some generalizations. Data in LCA software libraries represent average values, which may differ materially from the actual conditions of a particular plant or process. In addition, the same processes could show very different impact indicators, possibly also in the case of small differences in the initial boundaries considered. Guidelines to avoid or reduce these discrepancies exist, but the margin of freedom (and error) left to the investigator is still quite large.

2.5 Planetary Boundaries

Planetary Boundaries (Rockstrom et al., 2009, Steffen et al., 2015) is a global indicator system that seeks to assess and control some of the risk factors for the health of the planet. This framework identifies 9 biophysical processes; inside each of them, a dangerous boundary can be identified in order not be crossed. Scientists admit that the approximation margins are high, and it is difficult to find the exact thresholds, ie the values above which the process becomes particularly unstable. However, they consider it useful to fix a first, ‘proxy’ threshold, named boundary, located before the tipping point, which should provide a safety line to stay away from.

Planetary Boundaries (PB) indicators refer to the 9 subfields: Climate change (assessed either by carbon dioxide concentration or radiative forcing); Biodiversity loss (extinction rate of species); Biogeochemical (assessed either by nitrogen removed from the atmosphere, or phosphorus going into the ocean); Ocean acidification; Land use (surface converted to cropland); Freshwater; Stratospheric ozone depletion; Atmospheric aerosols; Chemical pollution.

Criticisms: Some critiques focus generally on the difficulty and arbitrariness of choosing relevant variables and setting “dangerous” thresholds. (Schlesinger, 2009) moves from this idea and pushes on, saying that "setting boundaries is fine, but waiting to act until we approach these limits simply allows us to continue with our bad habits until it's too late to change them." This critique seems to be out of focus, for at least two reasons. On the one hand, in general, the mere existence of an indicator is confused as the cause of the inertia of our bad habits. To assert this, it should be demonstrated that before the discrete indicators was invented, the world population behaved in an environmentally friendly way, which does not seem to be the case. Secondly, though PBs are "simple" indicators, they are among the less *attached* to their "jump discontinuity". As stated above, the boundaries represent simply a threshold of danger, which is not the tipping point, but is just the beginning of the red zone. Passed the boundary, (as, by the way, it is already the case for the first 3 fields), we would still have all the time to react.

3. Conclusions

Environmental/thermodynamic sustainability indicators are less problematic than socio-economic ones, since they are relatively simpler and more ‘objective’ to set, and goals are less influenced by ideological beliefs. Nevertheless, as we have seen above, they are not at all free of criticism of various kinds.

Some very strong criticisms of the alleged "lack of scientific rigor" of some indicators, though in some cases well-founded and indisputable, in some others seem to be a bit too biased. After all, if indicators are a science's effort to make itself accessible to non-specialists, one of the criteria by which to assess indicators should be their usefulness. Sustainability science, given its hybrid and interdisciplinary nature, should be more prone to check its impact on the real world. This is not an invitation to superficiality in the method; on the contrary, the quality standards of science must be as rigorous as possible. Possibly, researchers should also take into account the urgency of some issues, in which they are inexorably responsible, due to their role in society - even when they want to refuse it.

At a more general level, some criticize the use of indicators in policy-making by taking the example of paradoxical cases of policy-based evidence, which sometime takes the place of evidence-based policy. This wordplay denounces the misuse of science, bent for political ends. Although such events have happened and still happen, contributing to a feeling of mistrust from some people to scientific institutions, still they can hardly justify a tout-court rejection of knowledge as a tool to guide policy, especially since we do not have any other. Scientific knowledge is the most agreed, reviewable, re-arguable, communicable form to which we have come as a species. This in no ways makes it perfect, but, in the meantime, it is useful to walk in the dark.

Land requirements for Mediterranean diet: standard agriculture vs new agroecology

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Resilience indicators for sustainability are constructed by using multiple variables that include measurements of physical quantities (space, time, temperature, electric charge, energy, and so on). Such indicators can be considered as the monitoring tools that the system metabolism can use to monitor its health status (i.e. the capacity to adapt, spring back) and plan, organize the validation of its action course aimed at perpetuating itself (connected to semantic closure). This study aims at performing three investigations aimed at exploring three issues related to such indicators and their usage, coupling the investigation/meta-study of LCA/ecology studies and of available public data. The first investigation is about the sensitivity that indicators have to possibly reduced availability of high transformity forms of energy (electricity, most of all) i.e. how measurements of the quantities that define the indicators are affected (including the storage of necessary information) and what alternative definitions are present/available/developed. The second analysis addresses the possibility to include information from planetary energy constraints into resilience indicators to determine a "minimum society survival level" (intended as human group as part of the associated ecosystem) and to test the dependence of such definition on the human subgroup (society) by considering two different external referents and social validation schemes ("Industrialized/urban" and "less industrialized/rural "). The third study explores the connection of resilience indicators as tools to support changes in communities and the concept of leverage point i.e. the components and level of a complex system/metabolism where a small change can generate a large modification in the whole system.

Econometric Estimation of Energy Demand

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Abstract

This paper presents a relatively simple procedure to examine the responsiveness of energy demand to measures of economic activity and electricity price. We estimate the demand function for electricity both for households and for industry in 29 countries, mainly European countries, in the last 10 years, using a panel aggregate data.
Preliminary results suggest, as expected, that price has a negative significant effect on the electricity consumption. This is the case for both households and industry level for the same sample of countries. Our results also suggest that short-run elasticity of electricity consumption with respect to aggregate output seems to have been stable and unit elastic during the last decade. Moreover, price elasticity is more elastic and more stable in the industry sector than households are.

1. Introduction

Over the last two decades, the liberalization process in the electricity sector has spread worldwide. In the early 1990s the phenomenon started in a few countries (among others, United Kingdom, Norway and Australia) and subsequently it spread in the European Union (for instance in Spain, Germany and Italy). This wide diffusion is based upon the belief in the ability of competitive market forces to deliver efficiency gains for the whole economy.

The analysis of the effects of price changes on the demand for electricity is essential for planning and organizing the supply of electricity adequately. Accurate estimates of price and income elasticity are an important part of understanding effects of the policy for climate change mitigation in many countries. There are few existing studies estimating these important parameters across countries using a consistent dataset and methodology.
This is, to our knowledge, the first attempt at assessing demand parameters from aggregate households and industry data in a panel setting, while accommodating observed heterogeneity through country-specific coefficients.
The main results of this research show that electricity demand is inelastic with respect to its price in the short term, although there are differences between households and industrial demand. In the case of households demand, consumers react in the short term to increases in the price of electricity (although less than proportionally). Furthermore, there is a certain relationship between the level of per capita household income and the price elasticity of demand for electricity. Finally, we observe that the price elasticities of electricity demand are, on average, very robust to different values used in the article for income elasticity and price elasticity.
This paper organised as follows. In Section 2, the literature review is discussed. Section 3 concerns the electricity market liberalisation process. The econometric

methods is presented in Section 4, while results and discussion are presented in Section 5. Section 6 concludes.

2. Literature review

The economic literature about energy demand begins with the work of Houthakker (1951), who analyzes residential electricity consumption in the United Kingdom using cross-sectional data. Afterwards, Fisher and Kaysen (1962) investigate the residential and industrial electricity demand in the United States. They distinguish between the short term and the long term in residential demand. Subsequently, Baxter and Rees (1968) and Anderson (1971) focus on industrial electricity demand, while Houthakker and Taylor (1970), Wilson (1971) and Anderson (1973) address residential electricity demand. Among the first empirical studies Mount et al. (1973) use a panel data to study on the entire electricity demand, and Houthakker et al. (1974) use it in the context of residential demand. Afterwards, Lyman (1978) analyzes the residential, commercial and industrial demand for electricity, incorporating the use of data from companies and non-linear demand functions. However, In the 1990s when empirical literature about electricity demand becomes very extensive (see Madlener, 1996). Different approaches are proposed to estimate electricity demand. One method consists in estimating electricity demand through an aggregate model, using prices, income (or GNP) and climatic conditions as explanatory variables. Filippini (1999), García-Cerruti (2000), Hondroyiannis (2004), Holtedahl and Joutz (2004) and Narayan and Smyth (2005) use this specification for the case of residential demand. A second approach uses microeconomic data using to estimate as explanatory variables type of housing or characteristics of the home in the case of residential demand, as well as company size, type of industrial sector and intensity of electricity in production for industrial electricity demand to estimate electricity demand. Authors of this alternative method are Baker et al. (1989), Leth-Petersen (2002), Larsen and Nesbakken (2004) and Filippini and Pachauri (2004), for residential demand of electricity. For industrial electricity demand, it is worth mentioning of Woodland (1993), Doms and Dunne (1995) and Bjørner et al. (2001). Beenstock et al. (1999) cover both residential and industrial demand. Kamerschen and Porter (2004) analyze industrial, residential and aggregate demand, and Bose and Shukla (1999) estimate residential, industrial, agricultural and commercial demand. Beenstock et al. (1999) use quarterly data for Israel to compare and contrast three dynamic econometric methodologies for estimating the demand for electricity by households and industrial companies. The methodologies are the Dynamic Regression Model and two approaches to co-integration (OLS and Maximum Likelihood).

3. Overview of Energy market

The European Union long-term priority is to constitute “a competitive single EU electricity market” (European Commission, 2005). By means of three legislative packages (1996, 2003, 2009), the European Union gradually opened this sector for competition, aiming at an internal European electricity market. The first step towards a pan-European liberalised wholesale market was taken in 1996 with EU Directive 96/92/EC, which defined common rules for the generation, transmission and distribution of electricity and aimed at creating an efficient supranational European market (Gebhartd and Höffler, 2007). Subsequent electricity market directives (e.g.

2003/54/EC and 2009/72/EC) have also addressed emission targets for the electricity sector and specified paths to integrate renewable energy.

Directives adopted in 2003 established common rules for internal markets for electricity Deadlines were set for opening markets and allowing customers to choose their supplier: as of 1 July 2004 for business customers and as of 1 July 2007 for all consumers (including households). Certain countries anticipated the liberalization process, while others were much slower in adopting the necessary measures. Indeed, significant barriers to entry remain in many electricity markets as seen through the number of markets that are still dominated by (near) monopoly suppliers. In July 2009, the European Parliament and Council adopted a third package of legislative proposals aimed at ensuring a real and effective choice of suppliers, as well as benefits for customers. It is thought that increased transparency for electricity prices should help promote fair competition, by encouraging consumers to choose between different energy sources (oil, coal, natural gas and renewable energy sources) and different suppliers.

4. Empirical Framework

Energy demand describes a relationship between price (or income or some such economic variable) and quantity of energy either for an energy carrier (e.g. electricity).

Demand for energy can arise for different reasons. Households consume energy to satisfy certain needs and they do so by allocating their income among various competing needs so as to obtain the greatest degree of satisfaction from total expenditure. Industries and commercial users demand energy as an input of production and their objective is to minimize the total cost of production. Therefore the motivation is not same for the households and the productive users of energy and any analysis of energy demand should treat these categories separately.

The main determinants of demand are: price of the good, prices of related goods (including appliances), prices of other goods, disposable income of the consumer, preferences and tastes, etc. To facilitate the analysis, a convenient assumption (known as ceteris paribus) is made which holds other determinants constant (or unchanged) and the relation between price and the quantity of good consumed is considered.

4.1. Data source and variable measurements

Data for the analysis were drawn from Eurostat[1] covering 29 countries (see Appendix A). The basic country-level data GDP (Gross Domestic Product) is expressed in 1000 Euro, electricity consumption of households and industry are expressed in KWh and prices are €/KWh.

4.2. Econometric Technique

It is reasonable to assume that the level of energy consumption in general and electricity in particular depends not only on price and income in the current period but also in the previous periods, i.e. energy demand in this time period is correlated with its level in the previous period. A common way to model such dynamic relationship is

[1] http://ec.europa.eu/Eurostat

to adopt a partial adjustment model (Houthakker, 1980; Paul et al., 2009). Here it is assumed that the desired level of electricity consumption for each country *i* in period *t* depends multiplicatively on price and gdp (gross domestic product is used as proxy for income) according to:

$$elec_{it}^{*} = \alpha_1 (price_{it})^{\alpha_2} (gdp_{it})^{\alpha_3} \quad (1)$$

It is also assumed that the adjustment from actual to desired level of electricity consumption takes one period according to:

$$elec_{it} = (elec_{it}^{*})^{\theta} (elec_{it-1})^{1-\theta} \quad (2)$$

Inserting the desired level of electricity consumption from 1 into 2:

$$elec_{it} = \left[\alpha_1 (price_{it})^{\alpha_2} (gdp_{it})^{\alpha_3}\right]^{\theta} (elec_{it-1})^{1-\theta} \quad (3)$$

Taking logarithm:

$$\ln elec_{it} = \ln(\alpha_1 \theta) + \alpha_2 \theta \ln price_{it} + \alpha_3 \theta \ln(gdp_{it}) + (1-\theta)\ln(elec_{it-1}) \quad (4)$$

Simplifying and adding an error term v_{it} to capture the effects of unobserved factors the model can be rewritten as a simple dynamic panel data model:

$$\ln elect_{it} = \beta_1 + \beta_2 \ln price_{it} + \beta_3 \ln gdp_{it} + \beta_4 \ln elec_{it-1} + v_{it} \quad (5)$$

$\beta_4 = 1 - \theta = 0$ implies instantaneous adjustment and no dependence of electricity consumption on its lagged value. The short and long run price elasticities are then: β_2 and $\frac{\beta_2}{1-\beta_4}$ respectively. The error term, v_{it}, can be decompose into $v_{it} = u_i + e_{it}$. u_i is the panel unit specific error and e_{it} is the overall error that varies over time and panel units. It is assumed that $E(u_i) = E(e_{it}) = E(u_i e_{it}) = 0$.

The model in equation 5 will be estimated both at aggregate household and industry level. There are, however, some issues that need to be addressed when using panel data to estimate the parameters of the model. One issue is whether the data are stationary. There are different so called unit root tests developed for panel data. Here a Fisher type (Maddala and Wu, 1999; Choi, 2001) unit root test is used. According to Barbieri (2006, p.12) this type of test has several advantages. *"1) it does not require a balanced panel as in the case of IPS[2] test; 2) it can be carried out for any unit root test derived; 3) it is possible to use different lag lengths in the individual ADF[3] regression.* " Also, it is a non-parametric test so no specific distributional assumptions are made. One disadvantage is that that the p-values are based on Monte Carlo simulation. This

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[2] Im, Pesaran and Shin
[3] Augmented Dickey-Fuller

test assumes cross sectional independence. In the present case the test was conducted on demeaned series to alleviate the constraint imposed by this assumption. The results, not showed here, of the panel unit root test suggest that the null hypothesis that all panels contain unit roots can be rejected for all the variables in the model.

Next issue is to choose between the so called fixed effects (FE) and random effects (RE) models. In the present case there are several arguments that speak for a FE model. The sample is a set of European countries and assuming that the unit (country) specific error term is random and comes from a wider population is not convincing. A formal Hausman test rejects the RE model in favor of a FE model (see appendix B).

Another issue is the fact that the FE estimator for the coefficient of the (first) lag of the dependent variable (as one of the explanatory variables in the model) is downward biased and inconsistent when the number of time periods in the panel are fixed (Nickell, 1981). To overcome this problem a Stata routine, xtbcfe, that performs the iterative bootstrap-based bias correction for the fixed effects estimator in dynamic panels (De Vos et al., 2015) is used. The estimates from the FE model are not reported here, however, in fact when the estimates from the two estimation methods; FE and the alternative estimation method (xtbcfe) that uses bootstrap-based bias correction (De Vos et al., 2015) are compared the coefficient of the lagged electricity consumption estimated by the FE estimator is smaller which confirms the downward biasedness of the FE estimator. However, there might be an issue regarding whether there is any cross-sectional dependency, i.e. whether $E(e_{it}e_{jt})=0$. European countries are quite economically integrated. This can be tested by Pesaran's (2004) test implemented in Stata software (see De Hoyos and Sarafidis, 2006)). The results show cross-sectional dependence both for households and industry cases (See appendix C). For estimation of the models a bootstrap approach is used which is robust to contemporaneous cross sectional dependency (De Vos et al., 2015). The results seem to be reasonable. The effect of price is negative while the effect of GDP is positive. GDP can be interpreted as a proxy for income of the households and a proxy for aggregate output of industry.

5. Results and discussion

The estimation results are presented in Table 1.

Table 1: Estimation results based on xtbc_fe estimator (the dependent variable is $\ln elec_{it}$; log of electricity consumption)

	Household	Industry
$\ln price_{it}$	-0.050***	-0.119***
	(0.014)	(0.036)
$\ln gdp_{it}$	0.050**	0.106**
	(0.024)	(0.051)
$\ln elec_{it-1}$	0.807***	0.831***
	(0.060)	(0.076)
N	290	290

Notes:

i) Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
ii) Time dummies were included but were, in general, insignificant.

All the independent variables have a significant influence on the dependent variable at least at 5% level. The implied short and long run price and income elasticities are presented in Table 2. As expected the long run elasticities are greater in absolute value compared to the short run elasticities both for industry and households. On the long run there are more opportunities to change consumption behavior and also substitute to other alternatives. Also the results indicate that the elasticities of electricity consumption with respect to price and gdp are larger at the industry level both in the short and long run. This is probably due to the fact that at the industry level there is much greater cost awareness and saving on the cost of the electricity bill leads to change suppliers more frequently than households.

Also at the industry level the production levels are planned in advance and price changes lead to quicker response. The point estimate of the short run price elasticity is - 0.12 for the industry electricity consumption with a rather narrow 95% confidence interval while the point estimate of the long run price elasticity is - 0.7 but with a wider 95% confidence interval indicating a less precise estimate. For the households the short run price elasticity is - 0.05 which is quite small even though statistically significant. The long run price elasticity is greater in absolute value, - 0.26 and also statistically significant.

Table 2: Short and long run price elasticities (95% confidence interval in the parentheses)

	Short run	Long run
price (Industry)	- 0.12	- 0.70
	(- 0.19 - 0.05)	(- 1.18 - 0.23)
price (Household)	- 0.05	- 0.26
	(- 0.08 - 0.02)	(- 0.44 - 0.08)
gdp (Industry)	0.11	0.63
	(0.01 0.21)	(0.09 1.35)
gdp (Household)	0.05	0.26
	(0.00 0.10)	(0.06 0.45)

The point estimate of the short run elasticity of the industry electricity consumption with respect to GDP is 0.11 while the point estimate of the long run elasticity is 0.63 with a wide 95% confidence interval again indicating a less precise estimate. For the households the short run income elasticity is 0.05. The long run income elasticity is 0.26 with a wider 95% confidence interval.

6. Conclusions

In the study, we attempted to estimate the electricity demand the relationships for 29 countries in the last ten years of the liberalization of the European electricity market. Our analysis was based on panel modeling. The results show that the residential sector is less sensitive to price changes than industrial sector both in the short and long run. The results also suggest that the industrial sector is the quickest to alter their electricity consumption.

Appendix A- List of countries

Belgium	Croatia	Poland
Bulgaria	Italy	Portugal
Czech Republic	Cyprus	Romania
Denmark	Latvia	Slovenia
Germany	Lithuania	Slovakia
Estonia	Luxembourg	Finland
Ireland	Hungary	Sweden
Greece	Malta	United Kingdom
Spain	Netherlands	Norway
France	Austria	

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Assessment of the cultural heritage, in terms of eMergía, in agroecological systems of the central region Valle del Cauca-Colombia

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Abstract

The ingrained agricultural vocation of the Valle del Cauca has historically allowed for the preservation of areas and knowledge in diversified agricultural systems of peasant economy, in agroecological production, which support the expansionist struggle of sugar cane monoculture in the region. The study and assessment of resilience and real wealth of, both systems and their products, in agroecological systems recognizes the important interaction between the environmental, social, political, cultural and technological environments associated with such systems. The energy sustainability, with eMergia, of the tropical agroecosystems of the central zone of the Cauca Valley for 12 farms of six trails in three municipalities, gave% of Renewability (% R), between 78 to 89%, and Environmental load index ELR), from 0.008 to 0.012 The indices reflect the specific influence of the local energy inputs given by: i) the landscape that interacts with the agroecosystem, ii) biophysical, meteorological and climatic conditions, iii) the technological system and agricultural practices used, and iv) The historical and cultural information that identifies the agroecosystem. For the evaluation of this latter influence and its interrelation with the previous ones, it was proposed to introduce a group of contributions to eMergia flows, called the socio-cultural heritage (H) of the connections and interactions between agroecosystems and local societies. The eMergético index that relates the contributions of comparative cultural heritage to the net contribution of eMergia was denominated index of learning and teaching (% H), with values above 50% in all cases.

1. Introduction

Agricultural production systems, commonly called conventional, either on industrial scales or small farms (called farms) in family agriculture, are identified by the exclusive use of agrochemicals of chemical synthesis, purchase of improved seeds, dependence on external materials and services, Systems in monoculture and agronomic practices that cause Biodiversity loss, water pollution, celerity and severity in soil erosion. (Pimentel et al., 2005). Such systems of agricultural production affect the food sovereignty of the regions and the loss of traditional knowledge related to agronomic practices that make more efficient use of the resources available in the farms. It also accelerates the loss of the set of sociocultural assets and patrimony common to individuals in family farming systems treasured by tradition and in teaching-learning.

Agroecology emerges as an alternative fundamental science, to guide the conversion of conventional systems of agricultural production to diversified and self-sufficient agricultural systems (Altieri, 2010). It analyzes agricultural processes in an interdisciplinary way, where environmental, social, political, cultural and technological sciences interact (Gliessman, 1998). The vocation of Agroecology is the analysis of all type of agrarian processes in its broad sense, where mineral cycles, energy transformations, biological processes and socioeconomic relations are investigated and analyzed as a whole (Altieri, 1995)

The agricultural area in the central and north zone of the Cauca Valley in Colombia is characterized by the dominance of the industrial monoculture of sugarcane, expanding. The agricultural production of family basket products, both in conventional production and in agroecological production, are located in hillside areas, between 1000 and 1800 meters above sea level and their products are marketed in peasant markets organized weekly. These markets receive producers in the conventional system and recognized agroecological producers.

The agricultural production systems in agroecological production of the area (for the present study would be called agroecological farms), are characterized by: i) involve diversified agriculture, ii) reactivate the local economy, iii) contribute, to some extent, to the security and food sovereignty of the region, iv) are managed by small farmers who integrate the family, in the form of Family Agriculture v) have little adaptation to the natural physical environment, with agronomic and economic risks, due to the pressure of the use of resources in the surrounding cane monoculture, and vi) have very high conviction and personal appropriation of knowledge, transmitting agroecological thinking from generation to generation and through sociocultural interaction and information shared with the human society where the agroecosystem operates.

The integrative role of agroecology in managing agroecosystems in balance with their natural environment, harnessing knowledge and local cultural practices, socially equitable markets, and sovereignty of regional agricultural production requires the use of advanced sustainability assessment methodologies such as the energy valuation. Economic valuation is not enough to involve all the missionary components of agroecology.

Energy valuation is the closest estimation of the real value of the products obtained in a specific region and the agricultural yields in diversified and self-sufficient systems, identified in the conceptualization of Agroecology.

The eMergía synthesis designed by Odum (Odum, 1989, 1996, 2006) is a method of energy evaluation of systems where is counted,in solar eMergy whose unit is emjulios (sej), the available solar energy used directly and indirectly in the obtaining of products or services (Odum et al, 2012). The eMergética evaluation requires the calculation of indicators of environmental performance and sustainability of such systems, assessing the energy flows contributed by natural resources and energy flows of services and materials of the economy used in the agroecosystems. The total eMergy (U) used in the agroecological farms of the present study is composed of eMergia provided by materials and services purchased (F) and the "free" eMergy provided by the environment (I) (sun, rain, soil quality , Biodiversity and landscapes, etc.). Additionally, the contributions in eMergia given by the sociocultural heritage of agroecological systems are determined, (H), based on the energy of the permanent population in the agroecological farm for its metabolism, for the exchange of information and learning and transmission of agroecological thinking from generation to generation, information flows by the very essence of human DNA and energy and time required for the appropriation of knowledge.

2. Background of the assessment of human labor

The basic definition of a thermodynamic system refers to that delimited environment that exchanges mass, energy and information. The growing development of mechanisms and institutions specialized in information management and security emphasize the need to quantify information flows in productive systems, understanding that information can refer from the mechanisms of everyday language to complex systems of replication of genetic information used In ecosystems.

Abel (2010) refers that language and symbolic culture facilitate the transmission of culture from one person to another and from one generation to the next. In this sense there is an analogy with genetics, and like DNA, language and symbolic culture play a thermodynamic role in self-organized systems.

It is necessary to understand both human and natural domains, each in the context of the other, and it is important to develop sound management strategies that recognize and promote the vital interconnections between the two(Doherty et al.,(1993),Odum (1996)). The research of these authors analyzes the interaction and cultural preservation of a region with the management of natural resources. Both authors consider culture as the shared information of the human society through which it operates, and proposes the evaluation of eMergia flows based on inputs by territorial natural resources, energy of population metabolism, inverted energy for the exchange of information And learning among the population, information flows by the very essence of human DNA and the time required for the development of culture. In addition Odum (1996) predicts insufficiency in the valuation of human labor only by the quantification of labor in eMergético flow by services.

In the agroecological farms of the present study it is evident the "vocation" of Agroecology, given in the definition of (1995). The Agroecological culture is strengthened by the sociocultural interaction of information shared with the human society where the agroecosystem operates and major areas of influence. There is a wealth of knowledge regarding the design and efficient operation of agroecosystems and the conviction of personal appropriation of knowledge, the transmission of agroecological thinking from generation to generation.

Despite the abundance of research and literature on sustainable development, it is necessary to base and quantify the links between human well-being and the environment. (Cohen et. al., 2000).

3. Materials and methods

3.1. Context Evaluation

The study characterized 12 farms recognized in agroecological production, located in 3 municipalities: Andalucia, Buga and Seville. The agroecological farms are located between 1000 - 1600 masl. The agroecological qualification of the farms has been established by agroecological criteria and principles agreed by the same member farmers. Network of agroecological markets of Valle del Cauca, through the Participative System of Guarantees (GSP). The fieldwork I dedicate time of accompaniment inside and outside the agroecosystem and the record of information. In situ: i) growing areas, level of technification, agricultural and livestock practices, distribution of crop arrangements, seeds source (ii) community organization, (iii) family organization and knowledge transfer, (iv) agro-cultural practices, (v) farmers' income and marketing practices, vi) identification of environmental services and community empowerment. The characterization and typification of productive systems in the socio-cultural and economic context allowed the construction of flow diagrams of matter, energy and information as the example presented in figure 1.

The present study develops the methodology of eMergética synthesis for the systems in agroecological production and compares the results of flows of eMergy of a system in conventional production of the municipality of Seville. The materials and energy flow diagram of agroecosystems show their identity and architecture and point to the emergy inputs to the agrosystem by renewable (R), nonrenewable (N) natural resources, material economic resources (M) and Services (S). n order to determine the eMergia contributions given by the Sociocultural heritage of agroecological systems (H), the MESMIS methodology used initially, in sustainability assessments is initially adapted by Marta Astier (Astier et al., 2006), and this information is then translated In energy and eMergy contributions of the permanent population in the agroecological farm for its metabolism, energy in the time devoted to sociocultural interaction and presence in the market, energy of human DNA and the energy and time required for the appropriation of knowledge

The% R and ELR indexes are evaluated to determine sustainability within agroecological systems and comparatively between similar systems between municipalities. The eMergético index of learning and teaching (% H) that relates the contributions of cultural heritage related to the net contribution of eMergia (U), to determine the comparative influence in the agroecosystems given by: the number of permanent population in each agroecosystem, The time since the farm was reconverted to agroecological, time that the family that owns the agroecosystem dedicates to social interaction and teaching - learning.

The analysis also allows to identify and compare the real value, through the Transformity, of the products of the farms and the architecture in diverse agroecosystems.

3.2 Assessment of sociocultural heritage

This assessmente presented in two forms:

1) Qualifying, according to the MESMIS methodology, the vocation perceived in the agroecological producers visited and reflected in the acts of commitment that they sign as members of the Network of agroecological markets of Valle del Cauca, which says:

> "*As a member of the RED, To abide by the criteria established by the Network of Agroecological Markets of Valle del Cauca, assuming the responsibility of producing, marketing and sensitizing to the consumer friends and the community on the benefits of the production and consumption of agroecological products, guaranteeing the quality and continuity Of the supply in the market* "(Red Mercados, 2001)

Table 3, shows the criteria chosen in the study were built during the participation in the different organizational meetings of producers in their own regional markets, the monthly meeting of the Network of Markets, in individual dialogues with producers and their families and during the Iento. Each indicator is estimated separately and assigned a value from 1 to 10 (1 being lower and 10 being higher).

2) Assessment of sociocultural heritage In terms of eMergy

The producers and families of the 12 agroecological farms have adopted agroecological thinking and agroecological practices between 8 to 35 years ago. The personal and generational conviction of the producers for the agroecological alternative of production, allows them to have solid and diverse knowledge of agro-environmental sustainability, food security and sovereignty and conservation of biodiversity and traditions and customs in the management of agroecosystem and products. Family preservation and organizational consolidation (brought together by associations) enables continuous teaching.

Emergy flows (H_Hi) gathers the annual metabolic energy flows of the permanent population in the agroecological farm (Mi), use of energy for the exchange of information and learning and transmission of agroecological thinking from generation to generation (ISA_i), the flow of information by the very essence of human DNA (FGi) and the energy and time required for the appropriation of knowledge (ACi).

$$H_{Hi} = \sum Mi + ISA_i + FG_i + AC_i \quad (1)$$

$$M_{Hi} = f(P_i, t_j) \quad (2)$$

$$ISA_i = f(t_{is}) \quad (3)$$

$$FG_i = f(P_i, \text{DNA humano}, W_i, t_{ir}) \quad (4)$$

$$AC_i = f(P_i, NF_i, CC_T) \quad (5)$$

Where: P_i is a permanent population in each agroecosystem (including family and others); t_j time of permanence of the population in the agroecosystem; t_{is} = time the family that owns the agroecosystem devotes to the social interaction in the market, associations and other interactions; W_i = Size by weight of population; t_{ir} = Time of renovation in the generations that have built the agroecological farm (time since the farm was reconverted to agroecological); NF_i nevel of training achieved and appropriation of knowledge, by the permanence in the agroecosystem; y CC_T country capacities (Colombia) for technological training, undergraduate and postgraduate to its population.

4. Results

On average, the distribution of land use in the central and northern areas of the Cauca Valley corresponds to: Industrial crops 12%, pastures 36%, planting pasture.4%, Sowing areas peasant economy (including systems in agroecological production) 18%, Native forest 13%, guadua 2%, planting forests and other 15%. The sustainability of the productive systems under study was very marked by the influence of its border areas. In the municipality of Andalucia the influence of the industrial cultivation of cane by, the use of resources in that activity,% R is 80.55% for the case presented in table 1, and for other farms oscillates in 78%. Cost of water and electricity, as an external resource is high, and the provision of farms with living barriers to mitigate effects by fumigation. The practice of sowing live barriers is common in almost 90% of the agroecological systems evaluated. In Buga and Seville living barriers are required to separate from farms that practice family farming but in conventional systems. 6% of the farms evaluated limit with pastures for conventional extensive livestock. The higher % R implies great biodiversity in the farms and delimitation with forest.

The areas of agroecological systems vary from 1 to 6 hectares. Table 2 shows the normal subsystems: arrangement of banana, soybean, bean, corn; fruit trees of native species; vegetables; medicinal plants of common use to bring to the market and species of traditional knowledge of great use to the interior of the property for pest control. It distinguishes tropical species that characterize the remaining biodiversity in agroecological systems, such as cúrcuma, guamos, mafafa, cidra, bread tree, mamey, and others. It is characteristic in all the systems to use own native seeds and the preservation of varieties through exchanges.

The diversification of activities in the systems is dependent on the dynamics of complementary livestock production in agroecological systems, in addition the sowing of forest and fodder species as an ecological reserve, and atmospheric Nitrogen fixing species. The reason for these practices is because they are a source of fertilizer and crop supplies for crop management. Figure 1 shows the scheme of materials flow of support and dynamics of the agro-ecological systems visited.

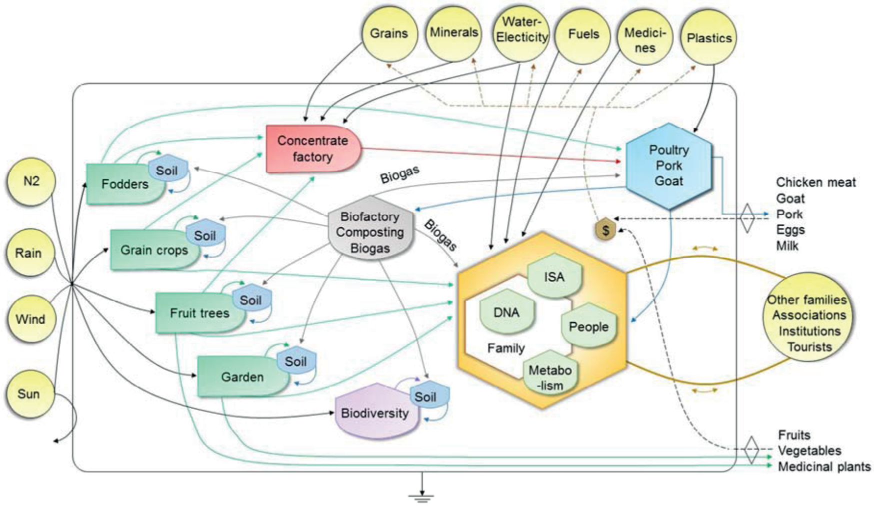

Figura 1. Flow diagram of materials, energy and information of agroecosystems, show their identity and architecture and indicate the eMergéticos contributions

Table 1 shows the eMergia aggregate flows for similar farms producing chicken meat, pigs, eggs, vegetables, fruits, and other products mentioned. The data in columns 3 and 8 compares in the municipality of Seville subsystems Cafe-Platano. The complete eMergía calculation supports and balance sheets can be reviewed in the PhD thesis document Agroecología de autor.

% R: ecological sustainability indicator indicates the percentage of renewable natural resources used in the production system. The difference is evident in conventional (9%) and agroecological (89.5%) production for the Cafe-banana arrangement in Seville, indicating greater ecological resilience, recycling of materials and lower production costs. ELR, represents the pressure exerted by productive systems on the ecosystem where it is located. Values close to zero indicate less environmental load of productive activity and greater sustainability of the productive process over time. In the case of agroecological systems values vary from 0.08 to 0.09 as%, while the indicator for conventional system is greater than 3.0

The H values on the farms of the three municipalities expressed as (H_{H2}) Includes the appropriation of knowledge and training at the technical and technological level in the permanent population of the farm. H participates in total emergia contributions between 40.06% and 55.2%. Minor values were obtained in properties with vulnerability due to the lack of generational relays. The high number of families on the farm raises %H. In all cases, the eMergy of information exchange and learning and transmission of agroecological thinking from generation to generation (ISA_i) is high. Expressed in the interview by the farmer: 67.2 hours / week devoted to activities of social interaction and learned information, which represents about 40% of the time.

Tabla 1. Flujos de emergía y porcentaje (%) de participación por componente para sistemas productivos agroecológicos en los municipios de Sevilla, Buga y Andalucía. Se presenta y compara los aportes eMergéticos de una finca en producción convencional en una finca de Sevilla

Emergy Inputs (Sej)	Resource	Conventional Production (sej) E13	**Agroecological production [1] Case Finca en Andalucía**				**% of each eMergia contribution relative to the total of (U) used..**		
			(H_{H1})		(H_{H2})				
			(sej) E13	%	(sej) E13	%	Sevilla	Buga	Anda lucia
Renewable Resources	**R**	723,5	465700	80,55	465700	49.63	89.5	90	78,0
Non-Renewable Resources	**N**	884,3	120	0,020	120	0,013	0.1	0.05	0.0
Cultural Heritage	**H**	0,0	72170	*12,48*	432168	46,06	55,2	50.1	40,06
External Materials	**M**	4180	741	0,128	741	0,079	1.3	1.3	1.3
External services	**S**	2250,9	39400	6,81	39400	4,19	7.5	8,	6,81
EMergy required (sej)	**U = I + F**	8039	578131		938160		U_i	U_i	U_i
Fraction of natural inputs resources of agroecosystem	(R/U)	0,09	0,8055				0,895	0,90	0,78
Fraction of Cultural inputs Heritage H_{H2i}	(H/U)	Indeter minate	Human capital of information		0,461		0,552	0,50	0,461
Eficiencia energética: Índices eMergéticos									
% Renewability of system	**%R**	9%	80, 55%				89,5 %	90%	78,0 %
Learning and teaching ratio (%H)	**(% H)**	Indeterm	Human capital of information		46,1%		55,2 %	50,1 %	40,06 %
Environmental loading ratio	**ELR**	> 3	0.086		0,088		0.08	0.08	0.09

[1] Values of annual eMergetic contributions in an agroecological farm in Andalusia. The eMergia flows for the same farm are presented using two magnitudes of the contribution (H), so: (H_{H1}) does not include the appropriation of knowledge and training at the technological level. It is considered as information capital of agroecosystem. (H_{H2}) Includes the appropriation of knowledge and training in the Sociocultural hetirage.

Table 2 presents the values that give identity to the products of the local agroecological farms. T expresses the eMergy that was necessary until obtaining the product per unit of energy of that product. This energy quality factor allows the real value of the products to be dimensioned, shows the correspondence between the energy inputs of the agroecosystem (in its physical environment, its socioeconomic and cultural structure) and the amount of energy (joules) obtained ss product.

Tabla 2. Example emergent indexes for agroecological properties in the municipalities of Buga, Andalucia and Seville in the Valle del Cauca. Arrangement in banana, corn, beans, soybeans

	Crops	Transformity T (sej/j)	%H	%R	ELR
Arrangements	M-S-P	6,49e+04	40,6	89.5	0.008
	F-M	1,03e+05	46,6	85.6	0.21
	M-S-P		53,5		
Fruit trees	Banana	4,67e+03	50,8	90.2	0.005
	Orange	5,67e+04	52,1	93.7	0.004
	Lemon	4,7e+04		93.7	0.004
	Papaya	1,61e+04		86.8	0.015
Vegetables	Cabbage, onion, carrot, tomato	7,10e+04		90.1	0.012
Medicinal plants	Yerbabuena, Paico, Marigold, etc	3,46e+05	55,6	90.4	0.011
Autochthonous Products	Guamas,cúrcuma, mafafa, mamey,	5,82e+04 3,09e+04	56.0 50,1	92	0.004

With the above data can be re-emphasized the value of origin of the products. For example, the banana in Seville has the same monetary value but its real value will be: i) in agroecological production: T = 4670 sej / J, H 50.8%, R 90.2% ELR 0.005, (ii) H undetermined,% R 9%, ELR greater than 3.

The data of table 3 allow to compare the sociocultural structure in agroecological farms. The criterion of greater relevance in all agroecological producers and their families is the criterion of participation in associations with a value of 10. This explains the tenacity in productive work with an evident conviction that it is necessary to replicate the transition from productive systems to patterns Of production and consumption renewable. The convergence of the producer and the market with their families increases the value of the complex connections and interactions between agroecosystems and societies. The maximum values of criterion (10) are reflected in the degree of confidence generated between producers and consumers in the markets, with a value of (10). The ties are strengthened with programmed agroecological views of consumers on the farms of the producers to learn the processes that occur within the farms. Figure 3 allows comparing these values: all criteria are above 7

Tabla 3. Criteria and social assessment in agroecological production systems for the 6 trails of the municipalities of Buga, Andalucia and Seville in the Valle del Cauca

Criteria /Sidewalk	Andalucia	Sevilla			Buga	
	Sidewalk 1	Sidewal 1	Sidewalk 2	Sidewal k 3	Sidewal k 1	Sidewal k 2
Strong family	8,4	10	10	8,3	7,5	10
Participation asociations	10	10	10	10	10	10
Intrafamily and neighborhood teaching practices	10	10	8,2	9,8	9,8	10
Convergence market	10	10	10	10	10	10
Participation children youths	9,2	8	10	10	8,3	10
Generational replacement	6	9,4	6,2	6,2	6,7	9,2
Degree of confidence producer consumer	10	10	10	10	10	10
Human relationships	9,4	10	9,4	9,4	9,4	9,4

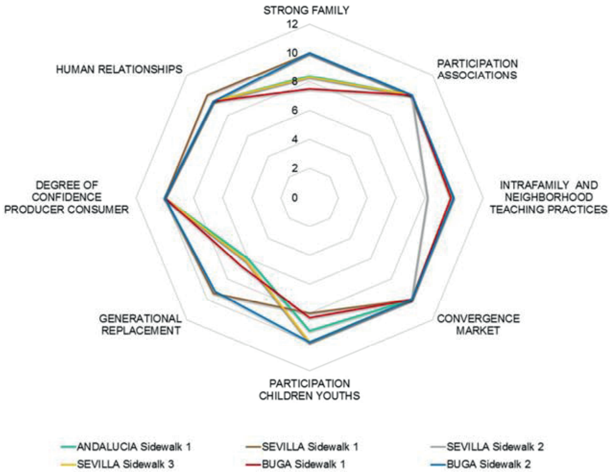

Figura 3. "Mesh" representative of the social valuation in agroecological production systems for the 6 trails of the municipalities of Buga, Andalucia and Seville in the Valle del Cauca

5. Conclusions

The world situation requires a diagnosis of systems to identify failures in the interaction of economy, nature and societies, as steps to be taken to find solutions. The numerical demonstrations presented in this paper invite us to rethink the evolution of human civilization to new patterns of renewable production and consumption.

For the agroecological producers of the three Valle del Cauca municipalities evaluated, those who participate in the table of healthy consumers, there are purposes of life agreements, committing to produce with quality and continuity. This commitment also extends to the consumer favoring ecosystems where biodiversity, water quality, knowledge recovery, preservation of species and seeds are conserved.

The supply of products in the markets must include true signs, such as labels of original value, that allow the consumer to decide which product to buy by comparatively checking the% R and ELR and% H consigned. This renewal in the form of consumption also requires knowledge in ecological sustainability, Nutraceuticals, and identification.

This research shows that farms are rich territories: their natural wealth provides people with a good quality of life, independence and stability that allow them to be resilient to the unpredictable fluctuations of the foreign economy and politics. The vocation of people for agroecology transcends boundaries.

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Navigating energy system options across the Global North-South

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Abstract
In the transformation of energy systems towards diversified and renewable sources, there is an increasing need for inter-sectoral coordination amongst a larger number of players. This requires significant system changes, and the reshaping of structures across scales. Sustainable energy transitions cover issues that range across political, economic, technical, and social domains. Although technological solutions are often the focus of research in sustainable energy transitions, they may not be the most relevant or critical aspect to address.

Approaches to sustainable development tend to prioritise the economic aspects, while marginalising, ignoring or externalising, the many social and ecological aspects. For example, intertemporal justice and global equity are often omitted in the interpretation of the "people, profit and planet" triple-bottom-line of sustainable development. This paper aims to facilitate sustainable energy transitions across the Global North-South divide, that requires a common space for more inclusivity, broader communication and dialogue, and the integration between top-down and bottom-up approaches.

Sustainable energy developments cover a range of renewable energy technologies implemented at various scales and configurations. For example, technologies generating electricity from wind, solar, biomass can be combined at household or industrial scales in an off-grid, mini-grid or grid tied system. A compass could assist navigating through this complexity and re-orienting society to a more sustainable energy system. Based on these challenges, we identify and define criteria that can provide coordination for a navigation system. In our mapping and assessment of different energy options across scales, we build on the existing classification schemes of energy transitions for climate change mitigation- encroachment, entrenchment, enclosure, exclusion- to incorporate aspects of energy regulation and socio-technical agency; such as negotiability and sufficiency.

Through scenarios or option spaces, an integrated perspective based on the sustainable business model archetype and the matrix for convivial technology, is showcased in order to enable sustainable energy transitions, de-growth and more sustainably coordinated consumption. This work can assist in identifying dynamic and integrated solutions between energy consumers and producers, and enable the planning and development of more decentralised and globally equitable energy systems. In addition, we propose incentives for intentional communities in the global North, off-grid communities in the global South, and peer-to-peer systems to exchange information on energy practices spanning the globe; that are needed to steer society to more sustainable and resilient energy systems.

Keywords: coordination and navigation system, cross-domain assessment, sustainable energy systems

1. Introduction

This work-in-progress assembles and evaluates different options for energy transitions using a mapping, coordinating and navigation system approach and incorporates a method from political economy. Currently, energy transition processes[1] progress at different paces and regulatory regimes across countries, and are driven by social aspects, jurisdiction and incentives (Kazhamiaka, 2017). A particular challenge is the parallel existence of established infrastructures that were designed in a top-down planning manner, with bottom-up new decentralised energy systems and small scale options arising. The distinction of different options and structures is necessary and called for by van Vliet (2005). Re-designing the roles and deciding on which technology options could support these shifts comprises our focus.

1 http://www.visionsandpathways.com/wp-content/uploads/2014/06/Twomey_Gaziulusoy_Innovation-and-Transition-Theory.pdf

Vetter (2017) reviewed the history of critiques of predominant concepts, which shaped the degrowth debate. From earlier references of the 1950s and 1960s, the "different theoretical backgrounds and explanations - all opposed technocratic societies and the alienation of human beings caused by the technocratic megamachine" are mentioned. The bridging of several theoretical approaches as opposed to integrating them was suggested by Geels (2016). The latter is not possible to realise according to them because of underlying differences in philosophies of science and ontological assumptions. UNEP (2016) described lessons from bottom-up approaches for sustainable lifestyles, of which energy supply and use systems form a part.

For the alignment of the two processes (top-down and bottom-up), the utility strategy and distributed generation of households, and community solar (CS) adoption were investigated (Curry, 2013; Funkhouser, 2015). Their common argument is the equity of subsidies and distribution of costs especially related to fixed cost recovery when some people opt out wholly or partially. Unfairness and misaligned incentives can externalise costs onto other stakeholders if mechanisms in a given jurisdiction system subsidise unequally (Curry, 2013). He also interpreted the current transition phase in the electric utility industry as being at a crossroads, similar to the situation of the telecom industry 20 years ago. In that context, the continued maintenance for landline telephone infrastructure is shared amongst less and less users with mobile telecom users not sharing the infrastructures of landline 'obsolete technology'. This analogy across telecom and power systems applies only when people would want to install their own autonomous off-grid solutions, as with one's own generation, one still uses the existing infrastructures when feeding into the grid.

While formerly integrated systems become liberalised, privatised and differentiation agendas reach down to the end consumer, new modes of operation can be envisioned and implemented. An example of desolidarisation from a utility system is provided by extreme case of off-grid or completely independent individual system unit. If this is done voluntarily in a country, where a grid connection would be no problem, reasons can include the perception of feeling of independence or avoiding rate increases. Cases where off-grid was not optional are described in Strenger's (2015) review of domestic life 're-assembly'[2] based on an ethnographic investigation.

Many examples of transformative changes in utility sectors with focus on the Netherlands and the UK, are provided integrating energy, water, and waste systems and are shaped by social practice theory as well as environmental innovations towards more sustainable modes of service provision (Vliet, 2005). In their case studies, either grid connections were upheld from the onset or reconnected after a trial phase of separation, due to economic, system efficiency and also ecological constraints for the case of water utility systems. While utility systems grew historically to provide to everyone equally, in this current era of choice, freedom and digitalisation, two trends emerged, on the one hand from the top-down and industry, and on the other hand from the bottom-up through energy cooperatives. Peer-to-peer (P2P) examples from different sections of the economy were reviewed and how structures are managed and upheld in this alternative system space were showcased (Bradley, 2015). Furthermore, a special case of unintended consequences, the

2 http://lifeoffgrid.ca/

rebound effect, was first explored in resource systems and technological applications, and recently extended onto financial, motivational, habitual, psychological, as well as industrial macroeconomic and structural categories (Santarius, 2015). From the comprehensive investigation of the rebound effect, a guidepost for an effective societal transformation balances the economic, psychological and social challenges with a necessary portion of eco-optimism.

The sharing of costs, benefits and responsibilities for either maintaining a sharing infrastructure that connects and provides transregional supply becomes more difficult the less it is used. When more people decide to opt out, system operators might partly be stranded. Scheer's (2005) conceptualisation of autonomy of energy systems is highlighted in a discussion of Solarzeitalter (solar era), where critique is raised against renewable energies especially with respect to individual energy autarchy due to their lack of solidarity (Eurosolar, 2016).

2. Coordination across Scales and Levels of (De-)Centralisation

While an individual subunit of a society could gain a sense of independence, autonomy, or autarchy in a system with increased self-sufficiency, this benefit is not necessarily ideal for other system levels. Considering the spectrum of options from a complete connectedness and a complete disconnectedness and self-sufficiency, risk factors and uncertainties from external forces might be reduced, but at what cost? Even though autarchy and self-reliance completely enable to self-determine and to be independent of future policy and regulatory changes, the control and transparency over one's own energy sources and uses comes at high monetary costs for a small individual subsystem. This changes with scale and the number of users.

We develop dimensions for a mapping system and apply it to energy autonomy scenarios. This enables a coordination across scales and different domains, making bottom-up and top-down processes work in synergy[3]. (Derry, 2016) Trade-offs must be examined between large centralised systems versus distributed de-centralised systems. The logic for either large-scale or small-scale system operations can be assessed in our option space. Comparing large scale, centralized systems with their:

- economy of scale
- delays emerging from raising feasibility studies, investment capital, policy debates, project planning
- wealth concentration and ownership

with distributed de-centralized systems, characterised by:

- greater material requirements (with higher potential for circularity)
- capacity and logistics
- agility and coordination requirements
- wealth redistribution and ownership

Supply chains for de-centralised systems, especially for technologically sophisticated electrical energy solutions often require external suppliers. Some established subsystems with already existing social structures and social capital (such as *stokvel,*

3 http://actionforesight.net/category/article/

a shared savings scheme in South African or other traditional communities) could grow into agents for transformative change in the energy system from the bottom up. Ownership, scale and operation do not necessarily need to coincide. An example would be a large wind or solar park, owned by a regional cooperative but contracting with a system operator, service provider, or market intermediary for day-to-day operations, while the coordination could reach up to long-term strategic planning. The criteria and results could help understand the costs and benefits of (de)centralised infrastructure designs to avoid an over- or under-dimensioning of supply and demand, with the borders blurring more with more prosumers entering the field.

What questions should be asked in order to foster collaboration and participation? These are central aspects of transdisciplinary endeavours. To enable discussion, communication and planning between top-down, centralised approaches and bottom-up distributed approaches requires a common space for planning, to avoid incorrect projections. In a future multi-scale holonic system that is composed of decentrally steered subsystems (Benz, 2015; Koestler, 1970; Kay, 1999), all the different solutions and stakeholders need to foster mutual awareness and planning, or under- or over-utilisation / capacities will be unavoidable. Prevailing uncertainties introduce risk for planning and require adaptive solutions, the opposite of technology lock-in of (usually but not necessarily only large-scale) infrastructure planning.

Our results will show which structures are enabling more solidary sub-systems, and how these can contribute to larger scales in a subsidiarity principle (Benz, 2015: cellular approach VDE study; Waltner-Tows, 2008). Adding to the determinism, freedom and self-sufficiency aspects, the location of control in infrastructure systems can be framed using innovative utility industry approaches on the scale of management and technology. (van Vliet, 2005) Different combinations are possible for these as well as for of infrastructure system transition structures (Bauknecht, 2015; Funcke, 2016; Bauknecht, 2013; Funcke, 2012).

Smaller-scale (not necessarily small-scale) and self-governed systems can lead to partly self-sufficient sub-systems, of which (electric) energy cooperatives are just an example. (Lambing, 2012) The scale and management of infrastructures under such a cooperative can take many forms and reduce uncertainty and risks through social solidarity or scale economics. Applying this logic to similar structural assessments to power systems, the needs and appropriateness of infrastructural requirements may differ or could be managed more flexibly for bottom-up generation.

A learning exercise across the Global North-South could be to initiate a peer-to-peer exchange, virtually, amongst families, sharing their practices, uses of and experiences with technologies in a transnational learning endeavour. Through this information sharing, an alternative perspective could be enabled, which could loosen up the prevailing ‘dogma’ of industrialised countries that maximum capacities have always to be provided by the systems of provision. It would provide an idea what about the possibilities of different resources management and could lead to questions of what is necessary and how it could be provided, and to explore how much can be done with how little. In off-grid systems, where economical and sufficiency questions need to be raised, this playful aspect is more serious.

Sufficiency and prioritisation of electricity uses were investigated for small-scale residential systems in Germany (Brosig, 2015).

3. Mapping Power Structures and Externalities

Several scenarios[4] applicable for Australia from a forum on future grid and energy system concerns were presented (Strengers, 2015). These included various degrees of involvement, participation and determination from the public, or the end consumer. Similar to her approach also taken in Strengers (2013), we too conceptualise an enlarged option space around humans and technology in energy infrastructures. We map dimensions of possible energy scenarios according to how they affect different stakeholders. We investigate the potentials for co-creation and co-ownership in the transition to sustainability using the example of electricity systems.

We start by highlighting a range of options for technical connectedness across central and decentral scales and structures. Next we add modes of operation, control and governance of the system, with extreme cases being off-grid or smart grid contexts. From the technical interconnections, we describe options for social connectedness, assembling illustrative sample cases. We suggest mechanisms for regulations based on the compass to be developed and provide an awareness of externalities and cost shifting, no matter if intended or unintended. The assessment of externalisation across dimensions can well be approached with the 4E method of Sovacool (2015). They described challenges associated with adaptation that are useful for analysing the dynamics of social-ecological systems (Binder, 2011). Furthermore, the energy justice decision-making framework provides a political-economic perspective in assessing environmental-economic trade-offs. (Sovacool, 2016)

The 4E (**e**nclosure - economic, **e**xclusion - political, **e**ncroachment - ecological, **e**ntrenchment - social) typology was developed to explain the political economy of climate change adaptation in practice. (Sovacool, 2015, Heffron, 2015) We elaborate on this method and correlate it with other tools (such as Bocken, 2014). Political economy considers distributional aspects, equality in terms of opportunity and access to decision-making processes and forums, ownership, as well as determination and control aspects of common pool resources. Different processes can lead to externalities at different paces, subtle or sudden. How inequalities can arise from an economist's perspective, was discussed through many examples of commodification of commons and encroachment (Standing, 2016). The 4E method can illustrate how political economic aspects are affected across several dimensions and across actors and can describe externalities. In their analysis of adaptation implementation planning and action, they identified four dimensions across scales. Each process can map a certain shift in balances of power related to different domains, such as administrative structures that allow public assets to move into private hands, hence to be enclosed.

4 (1) set and forget – where consumers rely on utilities (2) rise of the prosumer – where consumers actively design or customise solutions (3) leaving the grid – where consumers disconnect from the grid (4) renewables thrive – where storage plays a large part in entire electricity system.

Exclusion and enclosure are related, in that access can be limited, and people marginalised. The four dimensions are extended with additional aspects and their positive counterparts will be presented. For the re-assignment of roles and coordinating ownership, operations and strategic planning in changing energy systems, these dimensions can help to pinpoint risks for externalities. In addition to this, the matrix of convivial technologies (MCT) facilitates multi-faceted discussions on technology for society and impacts onto the society as a whole and also the relations with surrounding ecological systems (Vetter, 2017). Due to its different assessment and valuation system, the MCT can significantly reshape which technologies are considered as desirable for a given purpose, enabling qualitatively finely differentiated investigations. For the assessment of socio-technical dimensions of (de)central energy system structures, we adopt some aspects of the MCT.

Combining the dimensions adapted from the 4E method for the energy transition with the MCT assessment logic, we add appropriate dimensions for the option spaces. This can assist in processes for transformative change and specifically provide a dynamic view as well as a tracing of risks or potential externalities. Criteria for guidance and assessment of technology or legally or socially-driven scenarios can be provided by Vetter's method that is appropriate for bottom-up examples. The MCT dimensions and levels include: relatedness, access, adaptability, bio-interaction, appropriateness, and materials, production / manufacturing, use, infrastructure, respectively.

To address relevant questions for socio-technical infrastructure system operation and design, we detail the levels of connectedness, determinacy, control, and cooperation. We ask: How can individuals link directly or aggregate automatically, partially enabled through technologies? What are the technical and social consequences of several units being connected and infrastructures shared and how could one incentivise such cooperation? For the sake of illustration and analysis, we map options according to the following potentially overlapping criteria and possible dimensions for the compass coordinates to extend the MCT logic:

- (De)Centrality levels of structures and modes of operation
- Technology scales
- Social and technical / virtual (inter)connectedness
- Inter- and intra-level communication (within and between layers)
- Social aggregation, self(sufficiency), synergy aspects
- Self-determination / extension (boundaries from individual to collective)
- Positive counterparts of negative 4E

The collective systems formation may contain a social dimension. The modes or scales of such systems can all be present in either off-grid or connected contexts. A shift from a MEconomy to a WEconomy can be a critical ingredient in the alignment of individual and collective goal sets. MEconomy refers to an economy based on a ME-centric worldview, while WEconomy would be based on a WE-centric worldview. The former is focused on prioritising self-interest and relies on a worldview of a zero sum game, beginning with myself, then expanding to family, community, everyone else; while the latter is WE-centric and focused on prioritising balanced collective interest and a worldview of a positive sum game[5].

Through this, we provide an analytical conceptual tool to characterise different service providers' and business model archetypes (Bocken, 2014) and related infrastructure requirements. This assists not only the system operation and enables better planning, but also can contribute to more ecologically equal societies and hence increase wellbeing across scales (Hornborg, 2009, 2014).

We illustrate the use of the compass as to how one would navigate difficult energy transitions given a set of three selected exemplary contexts and cases across the global North-South for illustrating the compass as a theoretical tool. Those include the Desertec[6] project, the EWS[7] (ElektrizitätsWerke Schönau, a long-established, bottom-up organised renewable energy supply cooperative, a.k.a. the electricity rebels), and several implementations of the principle of solar power[8] as a service using a pay-as-you-go mode, which is an instantiation of the circular economy concept of product-as-service.

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5 See game theory: http://www.beyondintractability.org/essay/sum

6 http://www.desertec.org/

7 https://www.ews-schoenau.de/oekostrom/

8 http://helio100.sun.ac.za/#technology http://www.ishackproject.co.za http://graftlab.com/portfolio_page/solarkiosk/

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Productivity of Innovation in Biofuel Technologies

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Innovation is a key element in the belief in infinite economic growth. With consistent or increasing innovation, economies are able to use resources more efficiently and thus combat the consequences of increasing scarcity. This view, known as technological optimism, rests on the assumption that investments in innovation produce constant or increasing returns. If this is not so, the arguments underlying technological optimism are unsound. In the area of alternatives to fossil fuels, innovation is key to improving efficiency of production, and thus producing an affordable level of energy return on investment (EROI). We investigate the productivity of innovation in biofuel technologies using data from the U.S. Patent and Trademark Office. We also investigate whether there are technological spaces in biofuels that should be explored due to their high returns and/or low costs.

Ozone production and flows in the boundary layer and its impact on crop yields: an optimal ensemble estimation

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Abstract

The last decades have witnessed the emergence of an array of increasingly movements to harness science and technology in the quest for a transition toward sustainability. These movements take as their point of departure a widely shared view that the challenge of sustainable development is the reconciliation of society's development goals with the planet's environmental limits over the long term.

One of the most valuable contributions of science and technology to sustainable development comprises the improved delivery of yield-enhancing, land-saving accomplishments of the international agricultural research system. Nowadays, atmospheric pollution, i.e. the concentration of organic pollutants, aerosol loading and atmospheric oxidants, seriously threatens the yields of agricultural crops and it is unclear how the anthropogenic pressure on the biosphere can affect the resilience of the agriculture system or even cross a 'planetary boundary' (Rockström et al., 2009).

In this work we explore the capabilities of several statistical methods to combine model results in an ensemble sense and improve ozone predictions, under current and future scenarios, over the European region. The possibility to improve the predictive capabilities of existing models has fundamental implications both on the model forecasting ability necessary to sketch future scenarios and on the legislation to regulate the impact of air quality.

1. Introduction

Past research has shown that ozone alone or in combination with sulfur dioxide, and nitrogen dioxide is responsible for up to 90% of the crop losses in the U.S. caused by air pollution (Heck et al, 1982). Present day global relative yield losses are estimated to range between 7% and 12% for wheat, between 6% and 16% for soybean, between 3% and 4% for rice, and between 3% and 5% for maize (Van Dingenen, 2009). Under the 2030 current legislation (CLE) scenario, significant reductions in crop yields are predicted in Europe (soybean) and China (wheat) (Van Dingenen, 2009).

In order to assess the influence of air pollution on crop losses, the use of air quality models is of great importance. Since 2008 the Air Quality Model Evaluation International Initiative (AQMEII) coordinated by the EC/Joint Research Center and the US EPA has worked toward knowledge and experience sharing on air quality modeling in Europe and North America (Rao et al. 2008). This has been achieved by organizing coordinated case study analysis where several tens of models took part over the years. Within this context multi-model ensemble has been exercised proving to be very instrumental for a number of applications. The former consists in the combination of outcomes predicted by several models in the attempt to enhance the skill of the prediction when compared against an individual model realization (e.g. Galmarini et al., 2004, Riccio et al., 2011). The availability of regional scale air pollution models working at a high spatial and temporal resolution allows one to combine modeled ozone fields, exposure-response functions, crop location and growing season, to obtain regional estimates of crop losses.

In these last years, several results are obtained for combining the outcomes predicted by several models in the attempt to enhance the forecasting when compared against an individual model realization (Ciaramella et al., 2011; Galmarini et al., 2004; Riccio et al., 2012). In previous works (Potempski et al., 2010) an approach for the statistical analysis of multi-model ensemble results has been presented. The authors used a well-known statistical approach to multimodel data analysis, *Bayesian Model Averaging*, which is a standard method for combining predictive distributions from different sources. In Riccio et al. (2012) and Ciaramella et al. (2009) theoretical information approaches have been used for the reduction of data complexity in multimodel ensemble systems. The selection of a small subset of models, according to uncorrelation or mutual information distance criteria, usually suffices to achieve a statistical performance comparable to, or even better than, that achieved from the whole ensemble data set, thus providing a simpler description of ensemble results without sacrificing accuracy. Moreover, in Ciaramella et al. (2011) the authors explore a methodology, based on the combination of multiple temporal hierarchical agglomerations, for model comparisons in a multi-model ensemble context. They introduce a mechanism in which hierarchical agglomerations can easily combined by using a transitive consensus matrix and fuzzy similarity relations. The framework is amenable to easily incorporate observations that may become available during the course of the event, so as to improve the forecast by "projecting" observations onto the hierarchical combination of clusters.

In our case we have several sampling stations located all over Europe. Some data are *missing* and in particular, the measurements of ozone production is not available at a certain time points. To avoid an unsuccessful combination of multiple prediction models, and in particular for multiple temporal hierarchical agglomerations, in this work we focus on the statistical and machine learning methodologies for dealing with missing data

2. Methods

2.2 Imputation Process in Missing Data Time Series

The Imputation Process in Missing Data Time Series is organized as follows. Three steps form it: Initialization, Estimation, Maximization. In the first step, for each sequence $S = \{x_i,\ldots,x_f\}$ of missing data in time series, we replace the missing data of a sequence with the data generated from the linear interpolation between x_{i-1} and x_{f+1} that are the closest time series data to the sequence *S* with no missing data. If one value between x_{i-1} and x_{f+1} does not exist (this happens when the sequence is at the beginning or at the end of the time series), all missing data of the sequence are set to the remaining value. In the Estimation step it is performed the method of delays, whereas in the Maximization stage it is performed the prediction. At the end of the process, all missing data will be replaced by predicted values yielded in the Maximization stage and the steps Estimation and maximization will be repeated until the algorithm converges, i.e., no changes in the predicted value of time series occurs.

2.3 Methods of Delays

Given a time series, x(t), with (t = 1,2,...,l), we adopt an *autoregressive* model for describing it, i.e.,

$$x(t) = f(x(t-1),...,x(t-d+1)) + \varepsilon_t$$

The function f(·) is called the skeleton of the time series, and the term ε_t denotes the noise. In the above-mentioned autogressive model is crucial to fix the so-called model order (d − 1), namely how many past time series values are required to model correctly the autoregressive model. To this purpose, the method of delays (Eckmann and Ruelle, 1985; Packard et al., 1980), can be used for reconstructing the underlying dynamic system that has generated the time series, estimating, in this way, the model order. According to the methods of delays, the time series can be represented as a series of a set of data points $\Omega = \{X(t) : X(t) = [x(t),x(t-1),...,x(t-d+1)]\}$ in a *d*-dimensional space. If *d* is adequately large, between the manifold M obtained by the data points X(t) and the attractor U of the dynamic system that generated the time series, there is a diffeomorphism (i.e., there is a differentiable map m: M → U whose inverse exists and is differentiable). Therefore M and U share the same physical properties and it is adequate to study M to obtain all the required information on U. The Takens-Mané embedding theorem (Mañé, 1981) states that to obtain a faithful reconstruction of the system dynamics, it must be

$$2S + 1 \leq d \qquad (1)$$

where S is the dimension of the system attractor U and d is called the *Embedding Dimension* of the system. The most common parameter for characterizing an attractor is its dimension. A unique definition of the dimension has not been given, yet. In this paper, we use as definition of attractor dimension the Correlation Dimension, since it is quite easy to compute. However, we are aware that alternative more complex definitions can be used (Camastra and Staiano, 2016).

2.4 Prediction

In the prediction stage, the so-called skeleton of the time series f(·) is estimated, from data, using the so-called Support Vector Machine for Regression (SVR). The underlying idea behind SVR is to determine the regression curve using an ε-insensitive loss function that ignores errors that are within a certain distance from the actual values. The skeleton of the time series, using SVR, assumes the form

$$f(x) = \sum_i \beta_i K(x_i, x) + b \qquad (2)$$

where β_i, b, x_i are estimated from data, during the SVR training phase.

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Planetary boundaries in a changing climate system: how the Antarctic ozone trend responds to stratospheric dynamics?

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'Novel entities' are new substances, new forms of existing substances or modified life forms that have the potential for unwanted geophysical and/or biological effects. The introduction of novel entities to the environment is of concern at the global level when these entities exhibit (i) persistence, (ii) mobility across scales with consequent widespread distributions, and (iii) potential impacts on vital Earth-system processes or subsystems (Steffen et al., 2015). One of the most striking example of novel entity is the release of CFCs (chlorofluorocarbons) and related compounds, that were thought to be harmless but had unexpected, dramatic impacts on the stratospheric ozone layer. Nowadays, a challenge of the research community is to develop a well-established framework to assess the impact of chemical processes on the dynamical representation of the stratosphere. To this end, the Coupled Model Intercomparison Project Phase 5 (CMIP5) has been promoting a set of coordinated climate model experiments. CMIP5 notably provided a multi-model context for assessing the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds, and exploring the ability of models to predict climate on different time scales.

In this work we analyze how CMIP5 models represent the stratospheric dynamics and specifically the lower stratospheric cooling observed in summer since 1979 to 2001 over Antarctica, an important aspect associated with the austral springtime ozone hole. We found that models with a well-resolved and a chemical representation of the stratosphere better represent the lower stratospheric cooling, when compared to reanalyses. This implies better simulated long-term changes in the tropospheric jet and in the projection over the Southern Annular Mode (SAM) phase at the surface. Interestingly, we found that the stratosphere influences changes in the surface temperature of Southern Ocean with further implications for global oceanic circulation on interannual-to-decadal time scales. In future scenarios, the greenhouse gases increase plays a crucial role in driving high-emission scenario climate changes and the upper tropospheric warming at tropical latitudes is important as the polar lower stratospheric temperature trend in affecting summertime circulation multi-decadal trends. The Antarctic stratospheric future impact on the global ocean is also assessed for few model scenarios.

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Spatial assessment of solar and wind energy potential in Ecuador

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Abstract
Although renewable energy represents a large share of the electric energy generation sources in the Latin American region, non-conventional sources such as solar or wind energies have not represented a big part of their electric energy systems. The first step to promote the use of these sources is to identify the potential of each energy source in a region, task that can be estimated with the use of spatial tools such as Geographic Information Systems (GIS). This study describes a methodology to identify suitable areas for the development of non-conventional renewable energy projects, in order to estimate the maximum contribution of these technologies to a national electric energy system, and its applied to the Republic of Ecuador. The procedure describes seven steps required to properly identify the areas that best meet technical, social, environmental and economical requirements, using spatial layers gathered from various governmental institutions. As a result the areas with potential for development of RES projects have been identified, and classified in spatial layers according its technology and location. These results demonstrate large potential in the Andes and Insular regions, especially in the provinces of Loja, Pichincha and the Galapagos islands.

Keywords:
Renewable-Energy; GIS; Ecuador; Multi-Criteria Analysis

JEL codes:
O13; Q28; R32; Q42

1. Introduction

Ecuador is a country with a rich endowment of natural resources, and for decades has been able to use them to produce electricity. The dominant primary energy sources in the country are: oil, hydroelectricity and biomass, and historically, the energy demand has been dominated by oil, not only for domestic consumption but also for exporting; Oil is mainly consumed in the transportation sector and electricity generation. Besides hydropower and biomass, renewable energy has not played any significant role in the energy sector, although this trend has started to change thanks to the construction of some renewable energy projects, and the creation of public policies encouraging the development of clean energy generation projects (Castro, 2011).

Whilst the government has encouraged the expansion of renewable energies in the country, through the issuance of various regulations that promote their participation (CONELEC, 2011, 2013a-d, 2014), the share of non-conventional RES power plants in the national energy balance has not shown major increase in the last few years.

This study focuses on the assessment of potential locations for the implementation of non-conventional renewable energy projects, in order to estimate the maximum theoretical amount of energy they could contribute to the Ecuadorean's energy system. By using Geographic Information Systems (GIS) tools, this study seeks to identify suitable areas where RES power plants could potentially be settled and classifies the results by regions. The evaluation can be used as a starting point to select the best locations for the installation of resource measuring towers, in order to obtain detailed behavioral data from these sources.

2. Material and methods

The use of Geographic Information Systems (GIS) has been widely accepted on the location of suitable areas for the implantation of RES power plants. Studies about this subject can be found in almost every region of the planet. Nath et al. (2000) described in his study the necessary steps to perform a GIS project and the main factors to be taken into account to carry them out correctly for the goal of locating suitable areas.

Several studies use GIS tools to identifying suitable locations for RES, among them, we have reviewed Bravo et al. (2007), which evaluates the maximum potential ceiling of several renewable energy technologies in Spain; Ramachandra and Shruthi (2005), that assesses the potential of solar, wind, hydro and bio energies in the state of Karnataka, in India; Fluri (2009) for South Africa; Carrión et al. (2008); Jain et al. (2011); Eyad and Hrayshat (2009); Barman (2011); Kronshage et al. (2002); Ummel and Wheeler (2008); Affandi et al. (2013); Baban and Parry (2000); Gamboa and Munda (2006); Dimcev et al. (2011); Grassi et al. (2012); or Tegou et al. (2010).

2.1. Area of study

The Republic of Ecuador is located at the north-occidental region of South America, and it is surrounded by Colombia at the North, Peru at the South and East, and the Pacific Ocean at the West. The total territory covers an area of 256.4 thousand km^2 (PRO ECUADOR, 2011).

Since 2007, three Eolic power plants have been constructed in the country, two of them in the insular region of the Galapagos Islands, and the other in the Andean territory of Loja. The first wind power plant was constructed in the San Cristobal Island with an installed capacity of 2.4 MWp, with an average capacity factor of 15.2% in the last decade (ARCONEL, 2015). In 2013, the Villonaco Power plant started to operate with an installed capacity of 16.5 MWp, and has proven a capacity factor of 52.5%. By the end of 2014, the Baltra's Eolic Park was inaugurated with an installed capacity of 2.25 MWp.

The national installed solar photovoltaic capacity has reached in 2014 the summed capacity of 15.3 MWp, distributed in 24 plants located in various regions of the country (CONELEC, 2013).

2.2. Technologies considered for the study

Due to the availability of nationwide information from the solar and wind resources, the selected technologies for the analysis are: wind energy, solar photovoltaic, and concentrated solar power.

In the case of wind energy, the analysis takes into consideration only on-shore wind farms, because the resource raster files, containing national wind speeds, do not include wind speeds in marine regions of the country. According to various studies (Voivontas et al., 1998; Tegou et al, 2010) a wind project needs at least monthly average wind speeds of 5 meters per second (m/s), for a minimum period of 6 months per year, in order to become economically feasible.

Unlike solar photovoltaic, CSP plants take advantage of the heat of the sun to produce electricity, also called Solar Thermal Electricity (STE). Unfortunately for our country, equatorial regions tend to have large concentration of clouds and greenhouse gases, causing the dispersion of DNI. Luckily, DNI is considerably higher at higher elevations, where the path of sunrays finds fewer obstructions (IEA, 2015). Various studies (Affandi et al., 2013; Bravo et al., 2007) have estimated suitable DNI amounts between 4 and 6 KWh/m^2 per day, to be considered economically feasible.

2.3. Description of the methodology

Seven stages in the development of the project have been identified, performed in the following order: Identifying the requirements of project, formulation of specifications, development of the analytical framework, tracing data sources, organization and manipulation of the data, analysis of the data and outputs, and evaluation of results. For a detailed description of these, we refer the reader to Nath et al. (2000).

This study has identified as its primary need to identify potential sites for the construction of commercial scale renewable energy power plants, in Ecuador. Once the requirements of the project have been identified and understood, we have chosen ArcGIS 10.1, due to its high process reliability and availability of various spatial analysis tools.

We have then gathered the necessary data to be used in the study; it typically consists of raster images describing environmental, social, and economic information. These data can be obtained from primary sources like satellite and aerial imagery, or secondary sources like developed maps and layers of the region of study. Frequently, available layers are developed using diverse coordinate systems, which have to be standardized into a single reference system. The layers used for the analysis have been derived from the following basic data:

- Raster DEM of region 1 with pixel size of 30 meters, and DEM of region 2 with pixel size of 200 meters (SENPLADES, 2014).

- Raster layers with monthly and annual average wind speeds for both regions, at 30, 50, and 80 meters above ground level (MEER, 2013). Each layer has a pixel resolution of 200 meters.
- Raster layers with monthly and annual average direct, diffuse and global solar radiation, with 1 Km resolution, for region 1 (MEER, 2009); and a worldwide vector layer with monthly and annual average direct and global solar radiation, with 1º resolution, for region 2 (NASA SSE, 2015).
- Vector layers of nationwide urban settlements, rural communities, electric transmission lines, and primary and secondary roads, National Parks, among others (IGM, 2014).
- Vector layers of land cover from region 1 (MAGAP, 2014), and from region 2 (MAGAP, 2013).

Once all relevant information has been collected, it is necessary to organize and manipulate it according to the specifications defined previously. Here, we consider evaluation layers (EL), constraints layers (CL), and suitability layers (SL).

The seven evaluation layers considered were: resource potential, resource frequency, terrain slope, land cover, distance to transmission lines, distance to roads, and visual impact. Finally, once every EL has been generated, they have to be standardized to allow direct comparability between them (Tegou et al, 2010).

The constraint map is built to define the areas where a RES project cannot be developed, due to technical, environmental or social obstacles. For this study a total of eight restriction layers were identified: resource potential and frequency, wetlands, altitude, terrain slope, distance to transmission lines, distance to roads, distance to urban settlements, and national parks.

Once both EL and CL have been developed, they are merged. This process is performed, for each technology, to remove all the areas previously assumed to be unsuitable due to technical, social, or economic factors.

3. Results

The suitability layer, for each technology, contains pixels with grading values between zero (0) and one (1), demonstrating the percentage of suitability of any area located in region 1 and 2. The results of the suitability layers have been grouped according to their score, in order to identify the areas that are closer to meet all requirements.

This study has used the sensitivity analysis to identify the areas of influence of each layer, according to its factor. The resulting suitability layer has been compared with four case scenarios, described below:

Scenario 1 each layer is assigned the same weight,

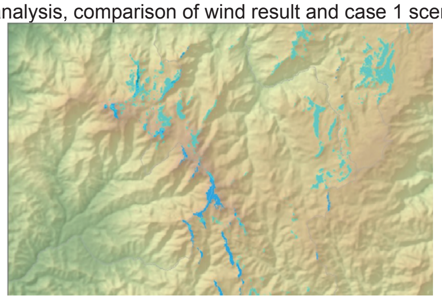
Scenario 2 the weights of the Environmental/Social factors are equal to zero (0),

Scenario 3 the weights of the Economical factors are equal to zero (0),

Scenario 4 the weights of both Environmental/Social and Economical factors are equal to zero (0). This scenario takes into consideration only Technical factors such as resource potential, frequency and terrain slope.

As it is seen in Figure 3.1., the wind suitability layer (light blue) locates suitable areas in different locations of the areas with high technical suitability (dark blue). As a result, it was possible to identify areas with effective results and eliminate areas without technical potential.

Figure 3.1.: Sensitivity analysis, comparison of wind result and case 1 scenario



Once the model has been performed, and its outcomes have been analyzed, its results will be summarized for the selection of the areas with highest suitability, to be selected for the installation of resource measurement towers. The location of suitable areas for the development of RES projects varies with each technology, and as seen in Figures 3.2., 3.3., and 3.4., the technology with greater areas around the country is solar photovoltaic, due to the increased availability of GHI. Wind and CSP technologies demonstrate targeted suitable locations in the Andean and Insular regions. From the results of the model, the five locations with greatest potential have been identified for each technology. These locations are described in Table 3.1., with its political and geographical location and coordinates.

Figure 3.2.: Suitability map of region 1, for CSP technology.

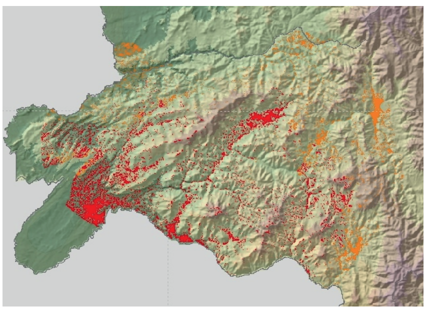


Figure 3.3.: Suitability map of region 1, for SPV technology.

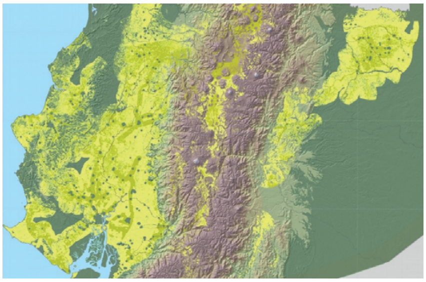


Figure 3.4.: Suitability map of region 1, for Wind technology.

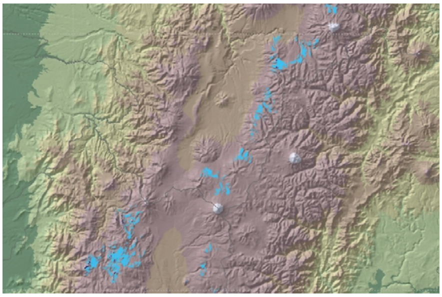


Table 3.1: Identified suitable areas with its geographical location and coordinates.

Location/Tech.	Province	Canton	Parish	Longitude	Latitude
Wind					
Location 1	Loja	Zapotillo	Garzareal	585743,086	9525545,551
Location 2	Loja	Macará	Sabiango	631913,196	9516445,626
Location 3	Loja	Paltas	Yamana	644176,686	9555578,338
Location 4	Cotopaxi	Sigchos	Sigchos	734696,074	9925032,210
Location 5	Pichincha	Quito	Calacali	780040,109	10004279,676
SPV					
Location 1	El Oro	Las Lajas	La Victoria	602964,343	9580813,287
Location 2	Imbabura	Ibarra	Salinas	817787,942	10052066,959
Location 3	Imbabura	A. Ante	Imbaya	815272,820	10042285,929
Location 4	Pichincha	Quito	Puembo	791950,455	9983915,914
Location 5	Sto. Domingo	Sto. Domingo	Alluriquí	715227,963	9971637,943
CSP					

Location 1	Loja	Loja	Loja	704229,557	9547187,38
Location 2	Cañar	Cañar	Juncal	722364,775	9719629,912
Location 3	Chimborazo	Alausí	Achupallas	756562,239	9751842,998
Location 4	Bolivar	Guaranda	San Simón	734691,737	9820846,469
Location 5	Cotopaxi	Pujilí	Zimbahua	728897,351	9899904,127

4. **Conclusions and recomendations**

Results show that the provinces with the most suitable areas are found in the Andean and Insular regions. Here we observe that the appropriate locations vary with each resource, however these are concentrated in a few provinces. The provinces of Loja, Pichincha, and Galapagos are the most benefited from the solar resource. It is in these provinces where optimal areas for implementation of SPV and CSP technologies are focused. The provinces getting benefited from wind resources are distributed in the Andean region, however identified potential locations are limited to the provinces of Loja, Cañar, Chimborazo, Cotopaxi and Pichincha.

In the model, resource potential and frequency were taken as layers of great importance (and weight), therefore it is of great importance to confirm the veracity of each resource, in order to obtain more trustworthy results. This can be achieved as the number of resource measurement towers increases across the country. Although the results have been confirmed by sensitivity analysis and field verification, the evaluation criteria used in the model to rate the importance of each layer can be modified, according to end user requirements.

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On how to integrate large shares of variable Renewables into the electricity system

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Abstract

The European Commission has set ambitious targets for increasing the share of electricity from renewable energy sources (RES), Due to these targets in recent years in the EU-28 countries electricity generation from variable sources like wind and solar has increased remarkably. In this paper, we show the conditions to integrate even larger quantities of variable RES into the electricity system by using market-based principles. The major conclusions of this analysis are: The transition towards a competitive and sustainable future electricity system will be based on an approach of "new thinking" which is to accept a paradigm shift in the whole electricity system. This includes switching to a more flexible and smarter system allowing a greater scope for demand participation, storage options and other flexibility measures. Developing such a system implies also that no politically motivated capacity mechanisms are needed.

1. Introduction

The European Commission has set ambitious targets for increasing the share of electricity from renewable energy sources (RES), e.g. [1]. In recent years in the EU-28 countries electricity generation from variable sources like wind and solar has increased remarkably, with Germany, Spain, Italy leading. Between 1997 and 2014 in the EU-28 "new" renewables excluding hydro grew from less than 1% to about 13%, mainly from wind, see Fig. 1. In addition, the EU has set further ambitious targets of a share of 27% (compared to about 14% in 2013) energy from RES by 2030. Consequently, also electricity generation from RES will grow further continuously, as documented in the National Renewable Energy Action Plans (NREAPs) despite it is not clear to which absolute level. The major motivation for this paper is to show what is needed for integrating these higher quantities into the electricity system.

Due to these developments, currently, the whole electricity system is at a crucial crossing. On the one hand, the way to a sustainable electricity system based mainly on RES could be paved in the next years. In this context we emphasize especially the considerable price decreases of PV which has brought this technology close to cost-effectiveness on household level, see [2] and [3]. On the other hand, there are forces which try to retain the old centralized fossil and nuclear-based generation planned economies. Centralized capacity payments (e.g. in France and England) should help to freeze this anachronistic pattern. A good survey on CM is provided in [4]. Also the EU has recognized this problem, see e.g. Koch [5] for an early contribution and [6] for a recent analysis.

The core objective of this paper is to provide insights how to integrate large quantities of variable RES-E into the electricity system by using market-based principles and how, straightforward, a sustainable electricity system could work. This market-based approach should ensure that competitive forces rather governmental interferences shape the future of the energy system and that in principle no comprehensive CM are necessary, see e.g. [6]. Our analysis is mainly based on Western European countries using data from Germany and Austria but in principle the findings of this analysis cam also be transformed to every other country. It builds on basics described in [2] and extends this paper towards variable renewables in general.

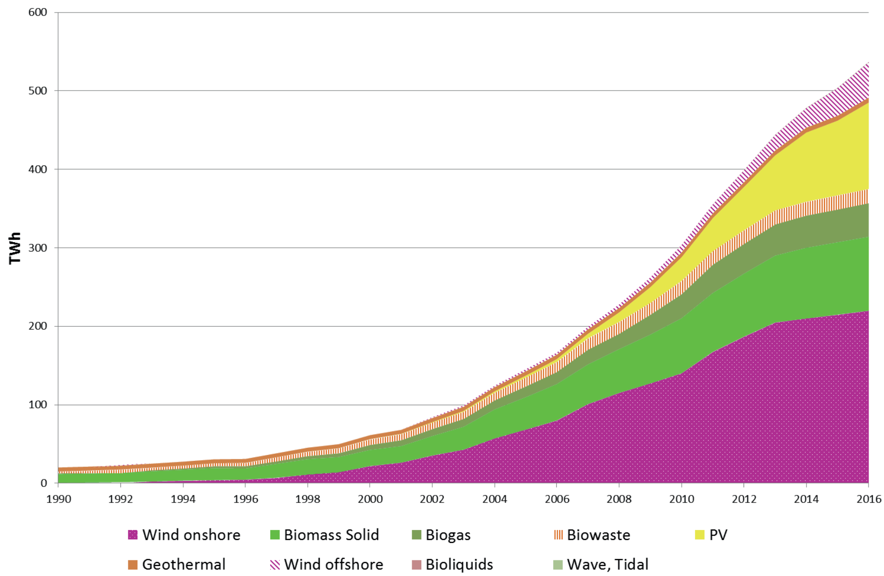

Figure 1. Development of electricity from “New” renewables (excluding hydro) in EU-28 between 1990-2014, in TWh (Source: EUROSTAT, own estimations, numbers for 2014 are preliminary)

2. Method of approach: How prices in electricity markets come about

To analyze the impact of variable RES on the prices in wholesale electricity markets it is first important to understand the current market rules and market structures, see [2]. Of key relevance is to understand how prices in European electricity markets currently come about. In this context it is important to look at the historical dynamics. The major change that took place after the liberalization was that prices were now expected to reflect the marginal costs of electricity generation (e.g., [6]). As shown in Fig 2, the intersection of the supply curve with demand determines the market clearing price at the price at the short-term marginal costs of the system. The curve Dt1 shows the demand curve at times of low demand e.g., at night and pt1 is the resulting (low) electricity price. Dt2 shows high demand times, e.g., at noon, and pt2 is the resulting (high) electricity price. The difference between pt2 and pt1 is the so-called price spread further described below. It provides useful information, for example, on the economic attractiveness of storage, which will be of high relevance in markets with large share of RES. Until recently, the price spread has been of interest mainly with respect to pumped storage. That is to say, during periods when prices are low, water can be pumped into reservoirs; while generating electricity when the opposite is true.

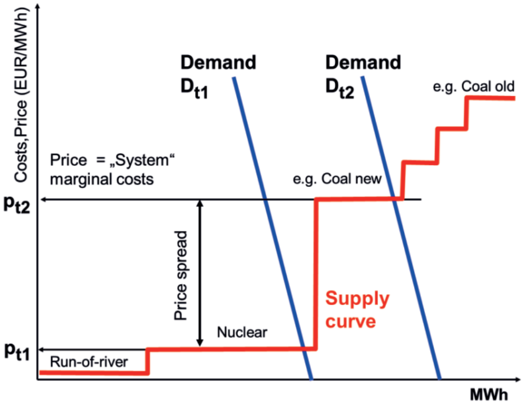

Figure 2. How prices come about in markets with a conventional merit order supply curve based on short-term marginal costs with conventional capacities (incl. large run-of-river hydro): intersection of supply curve and demand gives electricity price at two different points-of-time

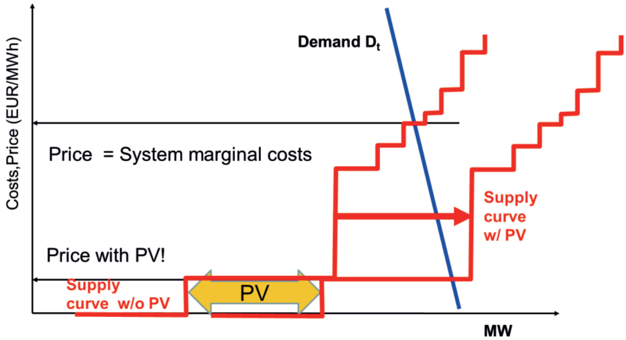

Figure 3. Merit order supply curve with and without additional PV capacities at on-peak time of a bright summer day with short term marginal costs for conventional capacities

3. How variable RES impact prices in electricity markets

The increase of renewables has started to impact spot prices, trading patterns and the dispatch of conventional generation by about 2011. The explanation is simple. Assume e.g. a sunny day with ample solar generation. Then the supply curve is shifted to the right as schematically shown in Fig 3, which essentially pushes nuclear and fossil fueled generation "out of the market", [26].

Of further relevance in this context is how the price spread in European markets will evolve in the future as larger amounts of PV, solar thermal and wind generation are added to the network. The consequence for electricity prices are shown in Fig. 4 where a hypothetical scenario with high levels of generation from wind, PV and run-of-river hydro plants over a week in summer are depicted using synthetic hourly data for an average year in Austria. The figure shows significant volatilities in electricity market prices with total costs charged for conventional capacities – black solid line – within very short-term time intervals.

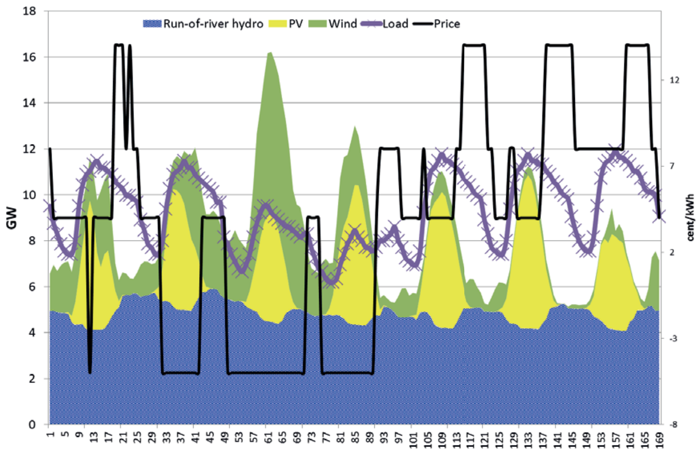

Figure 4. Development of variable RES from wind, PV and run-of-river hydro plants over a week in summer on an hourly base in comparison to demand and resulting electricity market prices with total costs charged for conventional capacities (Source: own analysis)

Our method of approach is based on the following principles: (i) Crucial is coverage of residual load (= difference between final electricity demand and generation provided by non-flexible electricity generation from variable RES as well as coal and nuclear power plants); this is modeled on an hourly base over a calendar year based on assumed RES electricity generation (ii) Deduction of available conventional and backup capacities including must-run (iii) flexibility on the demand side based on consumer behavior incl. flexibility instrument such as batteries etc.(iv) Hourly electricity prices equal to short-term marginal costs and scarcity rents.

Given the price pattern in Fig. 4 we are convinced that it would be attractive for some but sufficient power plant operators to stay in the market or even to construct a very efficient new plant! Moreover, these price spreads would provide incentives for new flexible solutions, see later. This would lead to the market model of a revised energy-only market. Fig, 5 shows the corresponding graph over a year classified by magnitude in decreasing order. As an example in Fig. 8 the profile of residual load in Austria 2013 and the development in a scenario up to 2030 with a much higher share of variable renewables is described. The major finding is that the duration curve of the residual load profile will become steeper and that the number of hours with excess generation will become higher. This effect will lead straightforward to higher price spreads and will also increase the attractiveness of storages and other flexibility options.

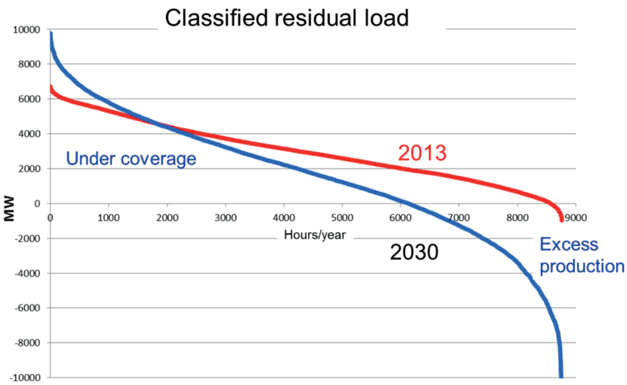

Figure 5. Development of residual load in Austria 2013 and in a scenario up to 2030 with high share of variable RES

For the area left on top there are in principle two options to be covered: By regulated capacity payments? Or by competition between supply-side and demand-side technologies and behaviour (incl. Storages, grid and other flexibility options)? Important remarks: Flexibility measure will contribute in a competitive way to reduce these price spikes and consequently the price spreads and lead to new equilibria between supply and demand!

4. Flexibility: The key term of the future

Our major findings for integrating large quantities of variable RES-E into the electricity system by using market-based principles are, that the following conditions have to be fulfilled,:

Of core relevance for integrating larger shares of RES-E in a competitive way is a pricing system in an energy-only market where the prices signal provide information on scarcity or excess capacities at every point-of-time (quarters of an hour);

Most important to balance variations in residual load is an optimal portfolio of flexibility options which already exists today:

- short-term and long-term storages such as batteries, hydro storages, or chemical storages like hydrogen or methane;
- Technical demand-side management measures conducted by utilities like cycling, load management, e.g. of cooling systems, see also [44];
- Demand response due to price signals mainly from large customers to price changes, time-of-use pricing
- Transmission grid extension leads_in principle to flatter load and flatter generation profiles;
- Smart grids: They allow variations in frequency (upwards and downwards regulation) and switch of voltage levels and contribute in this context to load balancing; How an interaction between these options could take place is shown in Fig. 6.

1) A key role in this new concept will play balancing groups. These are the entities which finally have to balance generation, flexibilities and demand options.

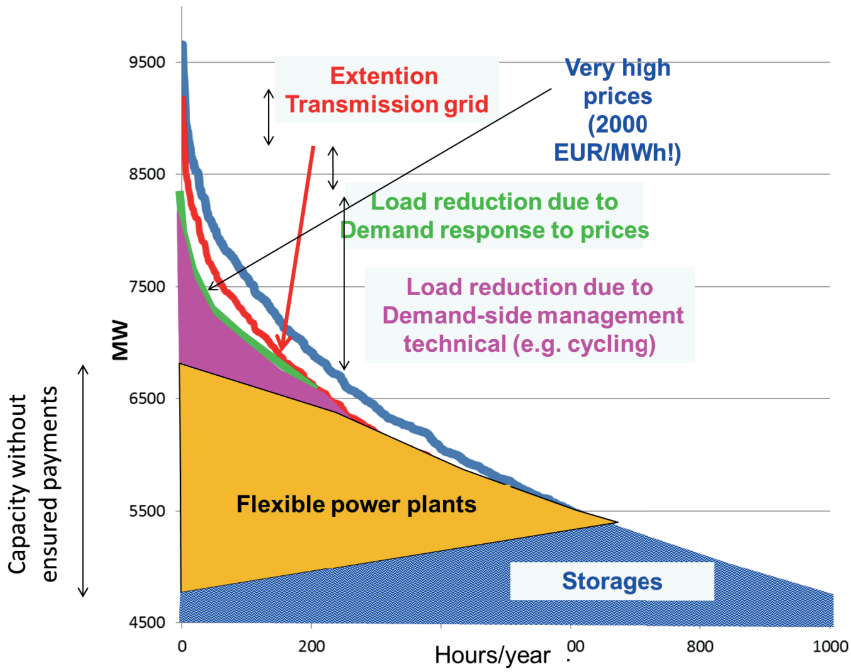

Figure 6. Market-based coverage of peak residual load in electricity markets

5. Conclusions

The major conclusion of our analysis are that the transition towards a competitive and sustainable future electricity system will be based on the following principle of "new thinking", which is to accept a paradigm shift of the whole electricity system - including switching from an inflexible and one-way system where variable load is met with changes in generation to a more flexible and smarter system allowing two-way electricity flows – to our understanding – a greater scope for demand participation by consumers needs to be included. In addition, suppliers (or balancing groups) are the most important part of the whole energy service providing chain, see also Fig. 15. The evolution of such a creative system of integration of RES in Western Europe may also serve as a role model for electricity supply systems largely based on RES in other countries world-wide.

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Extremophiles' relevance for the production of second generation bioethanol

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Abstract

The ever growing concerns about the threats of first generation bioethanol on food supplies and biodiversity have shifted the focus of research to second generation biofuel technologies. The second generation bioethanol's technologies provide sustainable energy without compromising food security and environment since they exploit non-food crops or non-food parts of crops and wastes of wood-based or food-based industries such as wood chips, skins and pulp from fruit pressing. The key step of the bioethanol's production processes is represented by the hydrolysis of the biomass to C5 and C6 sugars: such process relies on the use of bacterial enzymes that are mainly derived from extremophilic microorganisms. These microorganisms can be found in extreme environments, generally characterized by atypical temperature, pH, pressure, salinity, toxicity and radiation levels. Their enzymes (also named extremozymes) possess unique properties of considerable biotechnological significance that make them very useful for the industrial transformation of biomass to ethanol. In this report a survey of extremophiles and related enzymes that have been used for the bioconversion of waste biomass (not in competition with food chain) to bioethanol, is given.

1. Introduction

Bioethanol, i.e. ethanol produced by sugars' fermentation, is the most common liquid biofuel used in the world. In 2016, the bioethanol's world production reached 117.7 million m³ and a very similar value is also expected for 2017[1] (figure 1). Compared to the fossil fuels, bioethanol can reduce greenhouse gas emissions from 30 up to 85 % approximately, the variation is due to the different feedstock that can be used

[1] www.cropenergies.com/en/Home/

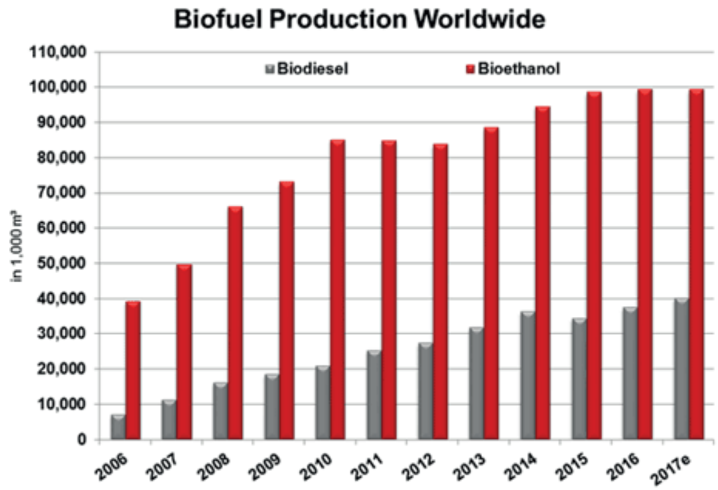

Fig. 1.1: Biodiesel and bioethanol world production. (Data from F.O. Lichts, Source: http://www.cropenergies.com/Pdf/en/Bioethanol/Markt/Dynamisches_Wachstum.pdf)

The main countries producing and using bioethanol are the United States of America and Brazil, that in the last years produced the 50.6 % and 23.8 % of 2017 global production, respectively. Bioethanol is mostly exploited in the fuel sector since about 84% of the total world production is used for transportation. In the USA, bioethanol is mainly used as a 10% petrol additive while in Brazil, it is used either as a pure fuel (E100) or as a 20 to 25 % volume blend with petrol. The production of bioethanol is now mainly based on the use of food crops (maize, sugar beet and sugar cane) as sources of sugars for the fermentation process. This kind of production also referred to as "first generation technology" is foreseen to reach a level of about 100 billion liters by 2022 (Saini et al. 2015) although the use of starchy or sugar raw materials like maize and sugar cane, is strongly in competition with the food chain. Moreover, starch and sucrose are insufficient to meet the ever growing need of bioethanol, and their cultivation for energy production has a negative impact on biodiversity besides being a possible cause of deforestation that would be required to have more farmland available. The concerns about the threats of first generation bioethanol on food chain and biodiversity have therefore shifted the focus of research to the so called "second generation technologies" that on the contrary, exploit non-food crops or non-food parts of crops and wastes of wood-based or food-based industries which represent a most abundant renewable organic component in the biosphere (Zucaro et al. 2016). Indeed, huge quantities of wastes, either lignocellulosic or starchy raw materials, are generated by industrial processes and agricultural practices and represent a cheap and renewable feedstock for bioethanol's production. Such agroindustrial residues (Nair et al. 2017**)** are rich sources of structural polysaccharides like cellulose, hemicellulose and starch that are a sustainable source of C5 and C6 sugars that can be fermented to bioethanol. Although the production of bioethanol from wastes could provide several benefits in terms of sustainability and environmental impact, the second generation technology is still immature and the research concerning all the aspects of the process, from the feedstock's pretreatment to the sugar's release and fermentation, is still ongoing. In this context extremophilic microorganism and their enzymes can afford feasible and cost-competitive processes for the conversion of waste biomass into ethanol. Extremophiles are microorganisms able to grow under extreme conditions of temperature, acidity, alkalinity or salinity, pressure and radiation; moreover, they produce an array of biomolecules, like for example enzymes, that possess unique properties that make them ideal for the harsh conditions of the industrial process of bioethanol's production. Compared to the analogue mesophiles-based processes, the bioethanol production process exploiting extremophilic microorganisms presents several advantages i.e. lower risk of microbial contamination, increase of reaction kinetics and product's yields and finally lower environmental impact. Overall, extremophiles and their enzymes have great potential for improving the process of bioconversion of waste biomass into bioethanol. In this report an overview of the role that extremophiles and their enzymes can play in biofuel production, with special emphasis on thermophilic organisms, is given.

2. Lignocellulosic biomass: the feedstock for second generation bioethanol

Huge amounts of lignocellulosic biomass are available as feedstock for second generation bioethanol. Such biomass includes non-food crops (like for example dedicated energy crops growing on marginal lands) and wastes affording significant quantities of cellulose and hemicellulose that in turn are the sources of monomer sugars to be fermented for bioethanol production (Nair et al. 2017; Zucaro et al. 2016). The main residues that could be exploited are wood product industry wastes, municipal solid waste and agriculture residues. Indeed, cellulose and lignocellulose can be recovered from wastes like wastepaper, coffee residues, livestock manure biosolids and sludges, wood waste biomass, sugar cane bagasse, corn or maize stover, rice straw, wheat straw and bran (Nair et al. 2017). The percentage of cellulose in these wastes can vary from about 20-40% w/w in rice, wheat and barley straw or in softwoods and hardwoods, up to 50-80% w/w in newspaper, cotton, flax and chemical pulps (Saini et al. 2015). The production of bioethanol starting from these raw materials can offer several environmental and economic advantages, nevertheless the biotechnology of second generation processes is still immature: extremophilic microorganisms and their enzymes can play a role in different stages of the bioethanol production like biomass polysaccharides degradation and sugar's fermentation, some examples of them will be illustrated in the following sections

2.1 Cellulases and hemicellulases from extremophiles for lignocellulose degradation.

Extremophiles are able to thrive in extreme environmental conditions and therefore they produce enzymes that are able to tolerate the harsh pH and temperature conditions typical of the industrial process of bioethanol production. The most used extremophlic species are the thermophilic bacteria, indeed many of them have been reported to produce either cellulases and hemicellulases activities, that are required for the breakdown of the cellulose and hemicellulose polymers in plants. Moreover, the exploitation of thermophilic bacteria for polysaccharides degradation offers different advantages like higher rates of hydrolysis and reduced risk of bacterial contamination. Cellulose is the main and most abundant structural polysaccharide that is found in plant kingdom, representing about 35–50% of plant dry weight; it is an homopolymer by β(1→4) linked D-glucopyranose units (Di Donato et al. 2014). Cellulose is a high-molecular weight linear polysaccharide made up of repeating cellobiose units. The complete depolymerization of cellulose can be accomplished by means of three kinds of enzymes i.e. endoglucanases that hydrolyze internal glycosidic bonds thus decreasing the polymer's chain length; exoglucanases that remove cellobiose units from either the reducing or non-reducing ends of the polymer; β-D-glucosidases that finally degrade cellobiose and cellodextrins to glucose (Berger et al. 2014). Different extremophilic bacterial species produce cellulase enzymes that are suitable catalyst increasing the rates of cellulose hydrolysis. Such bacterial species include mainly termophilic microorganisms that are members of the genera *Pyrococcus, Sulfolobus, Thermotoga, Geobacillus, Caldicellulosiruptor, Thermus,* and *Bacillus* (Berger et al. 2014). The other main polysaccharide component of lignocellulosic biomass is hemicellulose, a complex carbohydrate historically identified as the mixture of those polysaccharides extractable from higher plants tissues by means of hot aqueous alkaline solutions: hemicelluloses are a group of structurally different polysaccharides that can be distinguished in xylans, mannans, β -glucans and xyloglucans (Di Donato et al. 2014). The complete enzymatic deopolymerization of this complex network of polysaccharides requires the combined action of different enzyme activities like endo-β-1,4-xylanases, 1,4- β-xylosidases, β-L-arabinofuranosidases, β-glucuronidases, acetylxylan esterases, feruloyl esterases, endo-1,4-β- mannanases, β-1,4-mannosidases and endo-1,5-β-L-arabinosidases (Berger et al., 2014). Like cellulase producing extremophiles, also in the case of xylanases the most suitable enzymes are produced by thermophilic microorganisms. Indeed, xilanase produced by thermophilic bacteria or archaea can act at higher temperatures and extreme pH values typically required for the complete polymer's hydrolysis. Some examples f interesting xylanase can be found in thermostable, thermoalkalophilic, thermoacidophilic, and thermohalophilic species belonging to the genera *Pyrococcus, Dictyoglomus, Sulfolobus, Bacillus, Geobacillus, Thermotoga, Acidothermus, Cellulomonas, Paenibacillus, Thermoanaerobacterium, Actinomadura, Alicyclobacillus, Anoxybacillus, Nesterenkonia, Caldicellulosiruptor, Enterobacter, Caldanaerovirga, Clostridium, Rhodothermus, and Thermotoga* (Berger et al. 2014).

2.2 Sugars' fermentation to ethanol: ethanologenic thermophiles

The industrial process of sugar's fermentation is dominated by the use of *Saccharomyces cerevisiae* species, that is able to ferment only C6 sugars. Nevertheless, lignocellulosic biomass degradation also produces C5 sugars: this issue has been addressed by using recombinant strains of *S. cerevisiae* and of the bacterial species *Zymomonas* (Bibra et al. 2015). Interestingly, some thermophiles have been identified that are able not only to efficiently degrade cellulose and hemicellulose, but that can also readily ferment either the pentose and hexose sugars produced after the polysaccharides hydrolysis. The use of thermophilic strains also in the fermentation step could further improve the bioethanol production process since they can ferment sugars also at temperatures above 50°C thus avoiding the energy requiring step of cooling that is required when using yeasts for ethanol production. Several thermophilic species are under investigation as ethanologenic species, most of them belong to genera *Clostidria*, *Thermoanaerobacter* and *Geobacillus* (Taylor et al. 2009). The research in this field is still ongoing since some relevant issues remain to be addressed including increase of ethanol tolerance and reduction of side products generation. Nevertheless, the high ethanol yields (compared to the mesophilic yeast strains currently used) and the possibility to improve the economy of the process are pushing the development of engineered ethanologenic thermophiles that represent a very promising tool for the second generation bioethanol production.

3. Conclusions.

The production of first generation bioethanol is currently a well-established industrial process, nevertheless the high environmental and economic costs have prompted the search of alternative ways to ethanol generation. Indeed, the current process relies on the use of feedstock competing with food chain, like corn or sugar cane. Moreover, the industrial process of biomass conversion in ethanol is an energy requiring process, since different temperatures are required in the single steps of biomass degradation and fermentation. In this frame, the use of non-food biomass like lignocellulosic materials, the so called second generation process, is the most promising alternative foe the sustainable production of bioethanol. The bioconversion of lignocellulosic materials into ethanol involves a complex of enzymes including several types of cellulases and hemicellulases, required to degrade cellulose and hemicellulose, respectively, to monomer sugars. Several extremophilic bacteria, mostly thermophilic ones, have been reported to produce are able to produce either cellulase or hemicellulose activities that can act also at high temperatures thus assuring high rates of conversion and lowered risk f contamination. Moreover, some of these thermophilic species are under investigation for their ability to ferment not only C6 but also C5 sugars, another major drawback in the current industrial process. For such reasons, the exploitation of extremophilic microorganisms could represent a valuable tool for a sustainable second generation bioethanol's production, although the development of such a process still requires the development of the current biotechnology.

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Biohydrogen production from Solid Phase-Microbial Fuel Cell (SP-MFC) spent substrate: a preliminary study.

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Abstract

Bio-based waste management processes, like Anaerobic Digestion (AD) and Dark Fermentation (DF), couple waste treatment with energy production using natural processes based on microbial metabolism. In addition, Microbial Fuel Cells (MFCs) , like other Bio-Electrochemical Systems (BESs), couples the removal of organic load and mineral nutrients with the production of electric power and commodity chemicals. In this study the potential joined utilization of MFCs with AD and DF in a two-steps process has been investigated. Our results show an increase of biohydrogen (276 %) production from MFCs spent substrates in comparison to the untreated solid organic residues from the Organic Fraction of Municipal Solid Waste (OFMSW). MFCs, if adequately improved and scaled up, could merge DF in a more efficient and cost-effective bio-process for a sustainable waste management.

1. Introduction

1.1 Waste as a resource

It has been estimated that waste management contributes for about 3-5% to Green House Gases (GHGs) emission, mainly due to CH_4, CO_2 and N_2O escapes from open dumps. Additional CO_2 emissions are from upstream processes, like waste collection and transportation. In recent years, the interest of scientific community towards systems able to produce energy from waste residues in combination with a low environmental impacts treatment has significantly increased. If we consider just the organic waste from agriculture (crop residues), the global energy that could be produced is estimated to be about of 50 billion tons of oil equivalent (UNEP, 2010). The major issue is: *how can we exploit this resource minimizing the environmental impacts and costs*? One possibility is linked to the production of energy vectors (or biofuel - BioF) like methane and biohydrogen ($BioH_2$) from biomass to reduce dependence on Fossil Fuel (FF) and environmental impact associated with their usage: the replacement of FF by BioF has been proposed by the European Union (EU) as part of the strategy to mitigate GHGs emissions, to increase security of energy supply and to support the development of rural communities (Ryan et al., 2006).

1.2 Bioprocesses for waste treatment and valorization

1.2.1 Anaerobic Digestion and Dark Fermentation

Considering only the organic solid residues, the most commonly used technologies for their treatment and valorization are the Anaerobic Digestion (AD) and composting (UNEP, 2010). AD is a collection of biological processes by which various microorganisms break down biodegradable material under anaerobic conditions with 4 main steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. This bioconversion process produces a biogas (mainly consisting of CH_4 and CO_2) that can be used directly as fuel in energy conversion systems (e.g. cogeneration engine) or it can be upgraded to natural gas-quality biomethane. Finally, the nutrient-rich digestate, obtained at the end of the bioconversion process, can be also used as bio-fertilizer. If the organic component of the solid waste is rehabilitated into energy by AD, it will decrease the adverse impact on the environment and contribute to reduction in consumption of FF (Al-Zuhairi et al., 2015). For this reasons and also because it is considered a C-neutral BioF, biogas has aroused great interest (Zuo et al., 2015). In recent years, also $BioH_2$ is acquiring great interest being C-neutral and renewable, having a high energy content per unit mass and being easily converted into electricity by a Fuel Cell systems (FCs), giving water as the only byproduct of the combustion process (Florio et al., 2016). FCs are currently considered the ultimate solution for electricity production and automotive transportation (Ausiello et al., 2015).

1.2.2 Microbial Fuel Cells

Microbial Fuel Cells (MFCs) represent an emerging energy technology in which bacteria, while degrading the organic matter, exchange electrons with an anode placed in an anoxic/anaerobic environment. The electrons, then, flow through and external circuit till reaching a cathode where they react with an acceptor (usually the oxygen) and protons derived from the breakdown of the organic matter occurred at the anode compartment (Figure 1) (Nastro R.A et al., 2016; Pant D. et al, 2010).

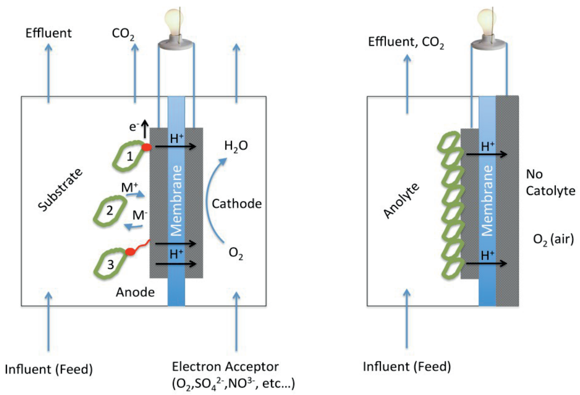

Fig.1: Schematic illustration of two-chamber and single chamber MFCs (Nastro R.A. et al., 2016).

The main outputs of MFCs are electricity and commodity chemicals. These last ones can be produced or not according to the feedstock and the microbial inoculum used, besides of the operational conditions realized in the MFC. Many different chemicals and several substrates, (such as wastewaters or solid organic residues from the Organic Fraction of Municipal Solid Waste (OFMSW)), can be used to feed MFCs (Jannelli N. et al., 2016; Chandrasekhar K. *et al.*, 2017; Pant et al., 2010)

1.3 Aim of the work

The coupling MFC to AD is a new concept of great interest that needs to be analysed and evaluated because only few studies have described in depth this approach (Schievano et al., 2016). In this work, the AD of spent Solid Substrate (SS) from a single chamber, air-cathode-MFC fed with the solid residues from OFMSW collected at an AD facility in Naples District, Italy (Nastro R.A. et al., 2015), was carried out for biogas and BioH_2 production.

2. Materials and Methods

2.1. MFC reactor assembly

The Membrane-less MFC reactor (SP-MFC) was crafted by modifying a glass jar with two graphite plates (AXF-5Q, POCO Graphite Inc., Texas, USA) used as electrodes (surface area of 56 cm^2). The cathode was directly exposed to ambient air through an air-tight hole on the top surface of the jar. The anode was placed at 2.5 cm from the cathode, in an anoxic environment. The feedstock was prepared using food leftovers collected in a treatment plant in Naples district (southern Italy), processing the OFMSW The organic mixture was used to produce a slurry composed of solid residues (40%) and a saline solution (60%), homogenated by a Stomacher 400 Circulator (Seward, Worthing, UK) for 20 seconds at 230 bpm, then anaerobically incubated at 15±2°C for 7 days to break the complex molecules present (cellulose, lignin, proteins and so on) accelerating the starting up of the MFCs (Rodrigo et al., 2009). The MFC run at 25°C (in-batch mode) for four weeks before the organic residues were sampled. The MFC performance was evaluated in terms of polarization behaviour, Current Density (CD) and Power Density (PD). Polarization curves were performed using external resistors in the range 1 MΩ - 100 Ω. Cell voltage was measured by means of a Keythley multimeter; the current corresponding to each external resistor was evaluated according to Ohm’s law. CD and PD were measured as current and power produced per m^2 of cathode surface and Kg of organic residues (specific CD and PD). Electrodes potential *vs* Ag/AgCl reference electrode was measured as well.

2.2 Anaerobic inoculum

Anaerobic inoculum (AI) was obtained from an AD plant and was kept at room temperature for 1 h prior to use.

2.3 AD batch experiments

Crimped Pyrex bottles with perforable butyl rubber septa were used as batch reactors. The reactors were filled with 15g (wet weight) of total feedstock (Florio et al., 2017). In particular, two separate vials with this respective composition were used: (1) 100% of SS from SP-MFC and (2) 100% of OFMSW as reference to evaluate the effect of SS in an AD process. Glass vials were inoculated with 7.5 %v/v (Florio et al., 2017) of AI (Inoculum/Substrate Ratio ISR 0.5, wet weight) and then distilled water was added to obtain a total working volume of 100 mL. During AD tests, the pH was eventually corrected with 5 %w/v Na_2CO_3 to restore the starting value of about 6.5-7. Anaerobic conditions were ensured by sparging the AD medium with nitrogen for 10 min, then vials were placed for 18 days in a basculating incubator (Infors HT Minitron, Bottmingen/Basel, Switzerland) at 150 rpm and 37 °C for mesophilic AD tests. Biogas volume was measured according to Pham *et al.* (2013) through intermittent measurements with syringe: the syringe was connected to the bioreactors by injecting the needle through the butyl septa, then drawing the plunger out until the pressure in the headspace dropped to ambient pressure. The volume of gas in the syringe was taken as a measurement of the biogas produced.

2.4 Analytical methods

Samples of liquid and gaseous phase from glass vials were collected for monitoring the AD bioconversion process. Microbial biomass was determined by optical absorbance at 600 nm (OD_{600}) of a sample (1:10 diluted). pH was measured using 740 pHmeter (WTW, Weilheim, Germany) and Chemical Oxygen Demand (COD) was evaluated with commercial KIT (HACH-Lange LCK 114). Biogas composition was determined by GC analysis using a HP 5890 series II equipped with a TCD detector and a double packed molecular sieves Porapack™ column (Ausiello et al., 2015).

3. Results

3.1 MFC performance

MFC potential was 264±20 mV at the cathode, showing a significant overpotential limiting the MFC performance. As to the anode, a value of -150±6 mV *vs* Ag/AgCl reference electrode was measured thus indicating the establishment of a reductive environment, as expected. MFC feedstock pH kept around neutrality along with the experiment (7.0±0.2), so no amendments were needed. The polarization and power curves revealed, after 21 days of operation, an optimal polarization behavior, with a maximum of PD of 1.75 mW/m^2·kg and a current 75 mA/m^2·kg (Figure 2).

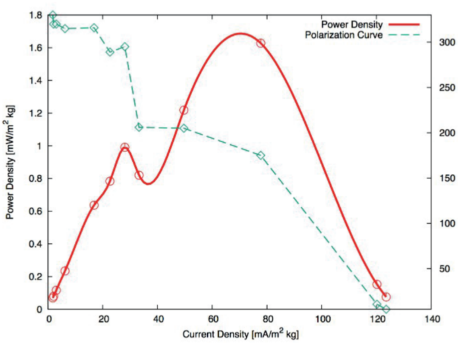

Fig.2: Power and polarization curves after 3 weeks of operation.

3.2 Biomethane and biohydrogen production

The results showed a significant increase in $BioH_2$ (276%) production in MFC spent substrate in comparison to solid residues from the OFMSW, with a yield of 14.13 ml/g and 3.76 ml/g respectively. In the OFMSW test, $BioH_2$ production is maximum during the first 48h of the bioconversion process, then it slow down and remain relatively low and constant until the process is completed (Figure 3). Instead, in the SS test $BioH_2$ production is relatively low in the first 96h of the process and increases considerably after this time, continuing until the end of the process, after 432 hours. Vice-versa, a higher methane yield was obtained from the OFMSW (Figure 4), with a 13.31 ml/g vs 4.56 ml/g obtained from SS-MFC.

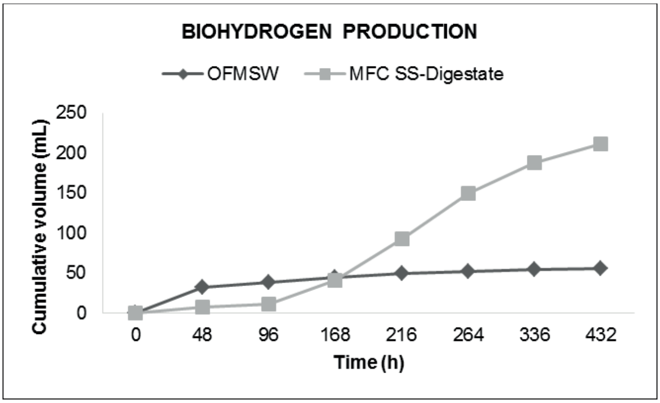

Fig.3: Cumulative $BioH_2$ production over time. OFMSW: solid residues from the OFMSW. MFC SS: Microbial Fuel Cell Solid Substrate

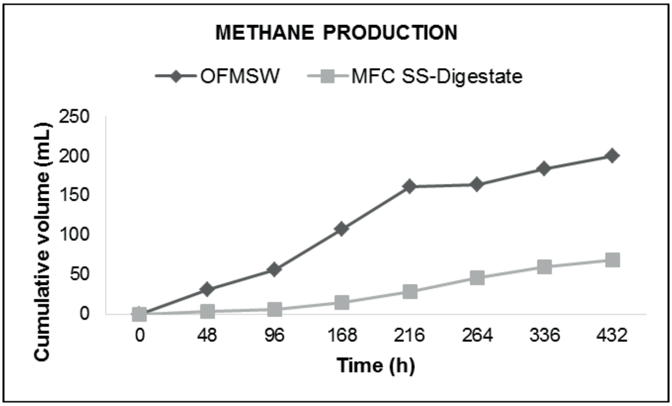

Fig.4: Cumulative methane production over time. OFMSW: solid residues from the OFMSW. MFC SS: Microbial Fuel Cell Solid Substrate.

This different trend was confirmed by the biogas composition: MFC-SS produced a biogas more rich in hydrogen, whose concentration increased from 51% to 79% between 96h and 264h of incubation. It is interesting to notice that if pH average value was 7.15±0.22 in the MFC-SS, a significantly lower value (4.85±0.9) was measured along with the AD experiment with the OFMSW residues in consequece of the different microbial metabolism established. As to the microbial biomass, the measure of OD_{600} revealed a higher biomass density along with the OFMSW AD in comparison to the SS-MFC, even though the growth trend is similar (Figure 6).

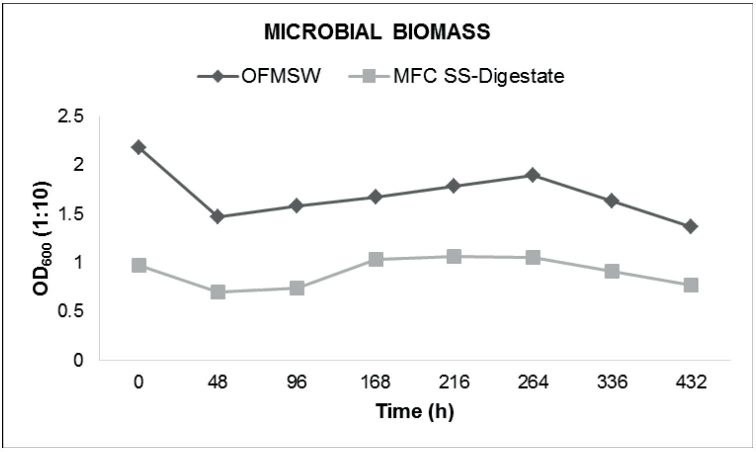

Fig.5: Biomass concentration trend over time along with the AD experiment with MFC-SS and OFMSW solid residues.

4. Conclusions

MFCs spent substrate revealed to be a better substrate for $BioH_2$ production than the OFMSW, with a higher yield and an increasing production over time. Even if the performances of the MFCs used in this preliminary experiments can be improved in terms of power and current densities, our results show that this newborn technology can open new possibilities in the energy recovery from organic waste.

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Using environmental accounting to operationalize the Planetary Boundaries framework at local scale in marine ecosystems

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Abstract

Nature provides vital resources in support of human economy and well-being. Due to the growth of world population and the growing size of human activities, resources consumption and related pressures on the environment are increasing. In this context, the Planetary Boundaries (PB) framework has been proposed to monitor trends with respect to Earth system critical environmental challenges. The PB approach is based on a set of biophysical boundaries defining a “safe operating space” at planetary scale, in which socio-economic development can take place while maintaining the resilience of the Earth system as a whole. Nonetheless, decisions on environmental management and natural resources use are generally not made at the planetary scale, but instead by managers, policy makers and other actors operating at national, regional, and local scales. To operationalize the PB framework it is necessary to scale down the approach, identifying ecosystem variables and related boundaries at local scale. This assessment can provide useful information to support local managers and policy makers in including global sustainability considerations in local environmental management. In this study, a number of biological, ecological, and socio-economic variables are identified to explore the performance and sustainability of human activities in marine ecosystems. Multi-criteria environmental accounting is proposed to explore the sustainability of marine ecosystems, taking into account biological and ecological features, environmental costs and impacts of human activities, as well as socio-economic aspects. Finally, we suggest to plot the calculated performance indicators against local carrying capacity values (i.e., local scale boundaries) to assess the extent of human impact and the possible transgression of threshold values over which the ecosystem stability and resilience are at risk.

1. Scientific background

1.1 Environmental accounting: scope and goals

Making nature’s value visible to humans has become a key issue (De Groot et al., 2012; Millennium Ecosystem Assessment, 2005; TEEB, 2010). Awareness about the importance of evaluating and protecting natural capital is continuously increasing, both among scientists and policy makers. Over the past few decades many attempts have been made to highlight the link between the functioning of ecosystems and human activities. In this context, the concept of ecosystem services (ES) was employed to remark the vital support provided by nature to human economy and well-being (Franzese et al., 2015). Ecosystem services have been defined as the benefits humans receive from natural environments (Häyhä and Franzese, 2014; MA, 2005) and classified in different ways. The most commonly used classification, provided by the Millennium Ecosystem Assessment (MA, 2005), is based on four categories: provisioning, regulating, supporting, and cultural services. Provisioning services include goods extracted from ecosystems (e.g., timber, fuel wood, food, and fibres).

Regulating services help maintaining the regulation of ecosystem processes (e.g., carbon sequestration and climate regulation, pest and disease control, and waste decomposition). Supporting services support the provision of all the other categories (e.g., photosynthesis, soil formation, and nutrient cycling) and cultural services contribute to spiritual welfare (e.g., recreational, spiritual, religious, and aesthetic experiences). More recently, the Common International Classification of Ecosystem Services (CICES) provided standardization in the way ecosystem services are described (www.cices.eu). This international classification is based on three main categories: provisioning, regulation and maintenance, and cultural ecosystem services.

While the generation of supporting and regulating services is mainly supported by natural renewable flows, provisioning and cultural services are exploited by using human-driven inputs (e.g., fossil fuels, chemicals, and machinery). The use of such inputs entails economic and environmental costs and impacts, at both local and global scales (Häyhä and Franzese, 2014; Odum, 1996). The environmental costs refer to the matter and energy flows invested to make the service available to the final user. The same matter and energy flows also generate emissions and environmental impacts.

A comprehensive understanding of interlinked ecological-economic systems requires the integration of different theoretical frameworks and accounting methods. In this context, environmental accounting represents a useful tool to assess the value of the stocks of natural capital, the flows of generated ES and the environmental costs and impacts associated to the delivery of ES. In particular, environmental accounting allows the assessment of multiple aspects among which the most relevant are sustained environmental costs, received benefits, and generated impacts.

1.2 The planetary boundaries approach

Consumption of natural resources at global scale has increased rapidly in recent decades, mainly driven by population growth, economic development, and lifestyle changes. These trends have been one of the main driver of changes in the Earth system causing several environmental problems. In this context, the Planetary Boundaries (PB) framework has been proposed to monitor trends with respect to Earth system-critical environmental challenges (Rockström et al., 2009; Häyhä et al., 2016). The PB approach is based on the setting of biophysical boundaries defining a “safe operating space” at planetary scale in which socio-economic development can take place while maintaining the resilience of the Earth system as a whole. Earth subsystems are particularly sensitive around critical values of certain variables. If thresholds are overcome, they can shift into new states often with serious negative consequences for humans.

Nine main PB have been identified that, if crossed, could generate unacceptable environmental change: climate change; rate of biodiversity loss; interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (Rockström et al., 2009).

Nonetheless, decisions on environmental management and natural resources use are generally not made at the planetary scale, but instead by managers, policy makers and other actors operating at national, regional, and local scales. For this reason, to operationalize the planetary boundaries framework, it is necessary to scale down the approach, identifying ecosystem variables and related boundaries at local scale.

1.3 Goal of the study

This study proposes a conceptual framework for translating the concept of PB to local implementation. In particular, a number of biological, ecological, and socio-economic variables are identified to explore the performance and sustainability of human activities in marine ecosystems. Several environmental accounting methods can be used in parallel to explore the sustainability of marine ecosystems, taking into account biological and ecological features, environmental costs and impacts of human activities associated to the delivery of ecosystem services, as well as socio-economic aspects. Finally, the calculated performance indicators can be plotted against local carrying capacity values (i.e., local scale boundaries) to assess the extent of human impact in relation to threshold values over which the ecosystem stability and resilience are at risk.

2. Methodological approach

In this paper, we suggest the use of a multi-criteria environmental accounting system based on the parallel application of different accounting methods that can be divided in two broad categories: 1) those that are focused on the amount of resources used per unit of generated product ("upstream" methods), and 2) those that deal with consequences of system's emissions ("downstream" methods). The former can provide useful insights about the hidden environmental costs and the performance of the investigated system. On the other hand, downstream methods are often more closely related to emissions and their contribution to environmental impact categories. The system under investigation is treated as a "black box" and a thorough inventory of both input and output flows to and from the system is firstly performed on its local scale. The inventory forms the common basis for all subsequent assessments carried out in parallel, thus ensuring the maximum consistency of input data and inherent assumptions.

The integrated assessment framework proposed in this paper explores the metabolism of marine ecosystems through the following main environmental accounting methods: Emergy Accounting, Material Flow Accounting, Embodied Energy Analysis, Eco-exergy analysis, Emissions accounting and impact categories (Recipe midpoint), Ecosystem services assessment.

These methods generate a set of biophysical indicators that can be integrated with other biological and socio-economic indicators, generating a large set of values connecting different disciplines and accounting methods. Finally, selected indicators can be plotted against local carrying capacity values (i.e., local scale boundaries) to assess to what extent human pressures can overcome threshold values over which the ecosystem stability and resilience are at risk.

3. Concluding remarks

Environmental accounting allows exploring the relationships between natural capital, ecosystem services, resources use, and human activities, providing indicators of environmental performance and sustainability useful to implement management schemes oriented to sustainable development.

In addition, the integrated assessment of environmental accounting indicators and critical boundaries calculated at local scale is suggested as a tool to support local managers and policy-makers towards the identification of policy targets in line with the biophysical limits set up at global scale.

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Environmental costs and impacts of food security in a changing world: The case of Lebanon

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Abstract

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Food security is negatively affected by a complexity of factors. These include unstable social and political environments that preclude sustainable economic growth, war and civil strife, macroeconomic imbalances in trade, natural resource constraints, poor human resource base, gender inequality, inadequate education, poor health, natural disasters, and the absence of good governance. All these factors contribute to either insufficient national food availability or insufficient access to food by households and individuals. A world population approaching 9 billion by 2050 and higher incomes in developing countries will lead to increased food demand, which means significant challenges to sustainable agricultural production. Food is a basic human need and therefore it is crucial to find ways to draw sustainable food production and consumption patterns. Food production is one of the most polluting everyday activities when impacts during product life cycles are considered. A large effort is needed to better understand the dynamics of an intertwined energy, environmental, and economic system such as agriculture and food production systems. An interdisciplinary effort is required to properly address the issue of food security considering different viewpoints, exploring in depth driving forces and environmental constraints associated with food production at local and global level. Critical to these investigations and ultimately to policy making is the need for multi-criteria assessment frameworks useful for evaluating sustainable production and consumption patterns, economic and environmental costs, and related impact on environment at different scales. In this study, we implement a multi-criteria assessment framework capable of taking into account different biophysical metrics to explore food production and security in Lebanon. Finally, different scenarios are drawn to assess how Syrian refugees are affecting food security in Lebanon.

Keywords: Food security; food production; environmental accounting; Lebanon.

1. Introduction

1.1 Food production in Lebanon

Lebanon is characterized by a Mediterranean climate along with fertile soils and a relative abundance of water which make it favorable for vegetables and fruit production.

The total land area that could be used for agricultural purposes is 332,000 hectares but currently 231,000 hectares are cultivated (MOA, 2014; Hatoum, 2006). From 2007 to 2010 there was a declining trend in the agricultural land use (Fig.1).

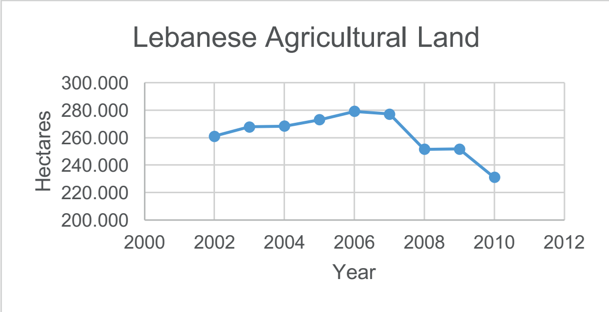

Fig. 1: Trend of Lebanese agricultural land in the period 2002-2010.

The main produced and consumed crops are potato, tomato, orange, apple, lemon, wheat, banana, grape, cucumber, and olive (MOA, 2009). The decrease of agricultural production has caused an increase of food prices. In addition, the increase of population has required that food demand has to be met by food imports (MOA, 2009; FAO, 2014) also contributing to prices raise. This result in an increase of social inequality and difficult access to food for poorer people (Farjalla *et al*., 2010). Currently about 24% of the Lebanese population is food insecure and about 75% of the total Syrian population living in Lebanon does not have adequate access to food (OCHA, 2015; USAID/iMMAP/FAO, 2015).

1.2 Goal of the study

Population growth, increased food demand and unsustainable food consumption patterns in Lebanon can contribute to environmental degradation. Therefore, efforts are required to address food security issues considering the environmental constraints associated with food production. The goal of this study is to assess the environmental costs and impacts of agricultural production in Lebanon. Scenarios are also drawn considering trends in agricultural production and consumption in relation to Syrian refugees.

2. Material and Methods

2.1 The area of study

The republic of Lebanon is a small Eastern Mediterranean country covering a total area of 10,452 km^2 and it is located between the Anti-Lebanon mountain ranges and the Mediterranean Sea (Bahn, 2017). The Mount Lebanon and the Anti-Lebanon chains run parallel to the Mediterranean Sea. The Lebanese length is almost three times its width and it narrows from the North to the South (Asmar, 2011). Lebanon borders Syria to the east and the north and Israel to the south. It has a coastline of 225 km and a total land boundary of 454 km. The country has a strategic position being located between the Arabian hinterland and the Mediterranean basin, explaining its history and ethnic diversity (WFP, 2013).

Lebanon is extremely diverse in terms of political and religious profiles. This diversity led to several conflicts, especially during the 1975-1990 civil war (UNHCR, 2013).

During this period Lebanon witnessed a significant reduction of government authority, physical and infrastructure damage, emigration of skilled labor and large losses of human capital and human lives (Markou and Stavri, 2005).

Lebanon is densely populated and the majority of population lives in urban areas (Asmar, 2011). Moreover, Lebanon population has increased in the last years (Fig. 2) and in 2016 it accounted for 6,006,668 people (out of which about 70% are Lebanese while 30% are refugees) (The World Bank, 2016).

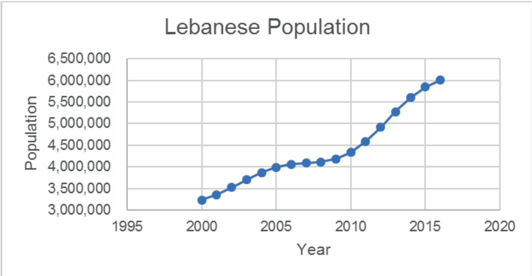

Fig. 2: Lebanese population trend in the last years.

Due to geographic proximity, Lebanon is one of the main destination for Syrian population trying to escape the civil war. However, Lebanon cannot adequately host refugees since institutions have a scarce capacity for the provision of essential services and security even for their own citizens (Dionigi, 2016).

Since the beginning of the Syrian crisis in 2011 the number of Syrian refugees increased until 2015 (Fig. 3), when the Lebanese Government decided to close its boarders (AEMS/MoEW/UNDP, 2017).

The official number of Syrian refugees in Lebanon is 1,500,000 constituting about 25% of the Lebanese population (MOE/EU/UNDP, 2015; AEMS/MoEW/UNDP, 2017). While most of Syrians are hosted within the Lebanese communities or living in rented accommodations, there are 223,965 individuals living in informal settlements in the North and the Bekaa regions (AEMS/MoEW/UNDP, 2017), where the main agricultural lands are available (Cortas, 2013; FAO, 2014).

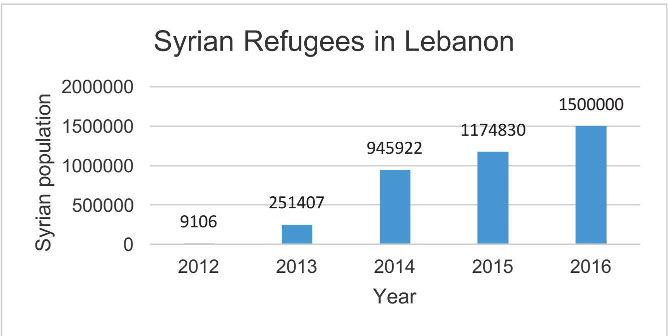

Fig. 3: Increase of Syrian refugees in Lebanon through time

2.2 The environmental accounting framework

In this study, a multi-criteria assessment framework of environmental accounting is implemented to assess the environmental performance and sustainability of agricultural production in Lebanon.

In the adopted framework, several evaluation methods are jointly applied to provide a comprehensive set of indicators at multiple scales and dimensions (Buonocore *et al*., 2014). These environmental accounting methods can be assigned to two broad categories: (1) “upstream methods” (i.e., Material Flow Accounting, Gross Energy Requirement, and Emergy Accounting) focusing on the cumulative amount of environmental resources supporting the investigated system, and (2) “downstream methods” (i.e., Recipe, CML 2001), more concerned with the consequences of the system’s emissions and their contribution to environmental impact categories (Buonocore *et al*., 2012). The system under investigation is treated as a “black box” and an inventory of both input and output flows to and from the system is firstly performed on its local scale. This inventory forms the common basis for the parallel application of all the environmental accounting methods.

In the present study, due to the lack of quantitative data about agricultural inputs and productions at national level, a bottom-up approach is used. Environmental costs and impacts are assessed first at local scale by investigating single local crops through field interviews. Then, the outcomes obtained for single crops are upscaled to the national level to assess the total environmental costs and impacts associated to agricultural production in Lebanon.

Table 1 shows the questionnaire that is used to interview local farmers in Lebanon. The collected data are used to organize the inventory of all the inputs and outputs flows associated to agricultural production.

Table 1: Questionnaire for data collection of the main Lebanese agricultural crops.

Input data for Lebanese crops per hectare per year				
Date:				
Farm:				
Contact:				
Crop type:				
Farm surface:		ha		
N.B.				
Inputs used are per hectare and on a yearly basis. Please specify if different.				
L.L stands for Lebanese Lira				
Output	**Raw Amount**	**Unit**	**Economic value**	**Unit**
Production		kg/year		L.L/kg
Input	**Raw Amount**	**Unit**	**Economic value**	**Unit**
Local Non-renewable resources				
1. Net loss of topsoil (soil erosion)		tons/year		
2. Water, irrigation		liter/year		L.L/liter
Imported Resources				
3. Gasoline		liter/year		L.L/liter
4. Diesel		liter/year		L.L/liter
5. Lubricants		liter/year		L.L/liter
6. Electricity usage		kWh/year		L.L./year
7. Machinery				L.L.
7.1. Type (Brand and Model)				
7.2. Quantity		number		
7.3. Weight		kg		
7.4. Hours of use per year		hrs/year		
8. Fertilizers		kg/year		L.L./year
9. Pesticides		kg/year		L.L./year
10. Seeds		kg/year		L.L/year
11. Labor		hours/year		L.L./year

3. Expected results

The environmental accounting framework will provide material, energy and emergy indicators showing the performance of all the investigated crops in terms of resources use. The accounting of emissions and their contribution to impact categories (i.e., climate change, eutrophication potential, human toxicity) will allow the estimation of the impacts generated by each agricultural crop.

The upscaling of the main results at national level will provide an overview of the total environmental costs and impacts associated to agricultural production in Lebanon.

Finally, the scenario analysis will help in assessing to what extent Syrian refugees influence the sustainability of agriculture in Lebanon.

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Life cycle assessment of wood-based bioenergy production: a case study in northern Italy

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Abstract

Increased environmental concerns, mainly related to global climate change and oil price increase, have drawn global attention to the dependence of human society on energy supply. Many European countries have chosen to respond to energy and environmental challenges by boosting bioenergy and renewable energy production. Ligno-cellulosic substrates are likely to provide an environmentally sound bioenergy option, especially when dealing with residues or waste. The use of wood biomass for energy production has the potential to deliver important benefits, among which an improved energy security due to a smaller dependence on fossil fuel supply, a reduction of greenhouse gas emissions, and a revitalization of rural economies connected to new job opportunities. However, bioenergy production from wood biomass also generates environmental costs and impacts that need to be assessed through environmental accounting methods. In this study, Life Cycle Assessment (LCA) is used to investigate the environmental performance and sustainability of a thermal power plant located in the municipality of Cavalese (Province of Trento, Italy) and utilizing wood residues from sawmills and forestry operations for heat and electricity generation. The environmental costs and impacts of bioenergy production are assessed with and without including the retrofit with new equipment and several modifications to the plant implemented to increase bioenergy production. Several LCA indicators, calculated per unit of delivered exergy before and after the plant adjustment, are compared and discussed.

1. Introduction

Increased environmental concerns, mainly related to global climate change and oil price increase, have drawn global attention to the dependence of human society on energy supply. Many countries have chosen to respond to energy and environmental challenges by boosting bioenergy and renewable energy production (Gan and Smith, 2011). On a global scale, renewable energy consumption grew by 28 % (from 17 EJ to 76 EJ) between 2005 and 2013 (EEA, 2016).

In 2013, electricity production by renewable energy in European countries was about 70761 kt of oil equivalent and, among different renewable energy options, biomass accounted for 12 % (EEA, 2016).

In Italy there are 89 wood biomass plants with a capacity greater than 1MW. The use of wood chips to produce renewable energy grew significantly since 2009, due to national incentives (http://www.basisbioenergy.eu/). Most plants are situated in northern Italy where the climate is colder and regional governments promoted the use of wood biomass for heating, in particular the exploitation of wood chips in small and medium size heating plants. Consequently, many small scale wood chips boilers and district heating plants have been installed in the area. The Province of Trento (North Italy) covers a surface of 620,668 ha and about 55% of the total area is covered by forests. The large presence of forests has determined an increasing interest in recycling wood biomass residues from forestry operations and sawmills for bioenergy production.

The use of local biomass for energy production has the potential to deliver important benefits: an improved energy security due to a smaller dependence on fossil fuel supply, a reduction of greenhouse gas emissions, a revitalization of rural economies connected to new job opportunities. Nevertheless, biomass exploitation also involves relevant environmental concerns. Several studies explored different aspects related to the sustainability of biomass use for energy production, among which: energy efficiency, land use, food demand and security, agricultural and processing inputs requirement, water use, and biodiversity protection (Sheehan, 2009; Petrou and Pappis, 2009; Cornelissen et al., 2012). However, significant research efforts are needed to fully evaluate environmental costs and impacts of alternative bioenergy production technologies by means of multi-method assessment frameworks (Buonocore et al., 2012; 2014; Nikodinoska et al., 2017).
Life Cycle Assessment (LCA) is a methodology for evaluating environmental costs and impacts associated with all the stages of a product's life from-cradle-to-grave. LCA has been widely adopted as an analytical tool to explore the environmental performance and sustainability of bioenergy production systems (Fazio and Monti, 2011; González-García et al., 2012; Welfe et al., 2017).
In this study, LCA framework was used to investigate environmental costs and impacts of a thermal power plant located in the municipality of Cavalese (Province of Trento, Italy) and utilizing wood residues from sawmills and forestry operations. The environmental costs and impacts of bioenergy production were assessed with and without including the retrofit with new equipment and several modifications to the plant implemented to increase heat and electricity production.

2. Materials and method

2.1 The thermal power plant

The thermal power plant "Bioenergiafiemme", investigated in this study, is located in the municipality of Cavalese (North Italy) and is mainly powered by wood chips from industrial processes and forestry, both produced at local level. In 2011, the plant was equipped with two boilers powered by wood biomass and with a total nominal power of 4 MW. The annual wood chips consumption of the plant was 4.48E06 kg and the annual heat and electricity productions were 2.52E07 and 6.56E6 kWh. In 2015, new equipment and several modifications to the plant implemented to increase bioenergy production. In particular, an additional wood biomass boiler was added connected to an Organic Rankine Cycle (ORC) module for increasing heat and electricity generation.
For this reason, the annual wood chips consumption of the plant became 7.86E06 kg and the annual heat and electricity productions were 3.06E07 and 1.09E07 kWh.

2.2 Life cycle assessment

This study was performed by applying the Life Cycle Assessment method (LCA) to empirical foreground data collected on - field by the authors. LCA is a tool for assessing the potential environmental impacts and resources used throughout a product's lifecycle, from raw material acquisition, via production and use phases, to waste management, from the so-called "cradle-to-grave" perspective (ISO 14040, 2006; ILCD, 2012). All activities and processes result in environmental impacts due to consumption of resources, emissions of substances into the natural environment, and other environmental exchanges. LCA allows technology comparisons in terms of environmental burden, providing valuable insights about the environmental performance of different technologies. Although developments of the tool continue to be achieved, International Standards of the ISO 14000 series provide a consensus framework for standardized LCAs (ISO 14040, 2006; ISO 14044,2006). The ILCD Handbook (ILCD, 2012), stemming from the ISO14040-44 standards, confirms the importance and the role of LCA as a decision-supporting tool in contexts ranging from product development to policy making. According to the ILCD handbook, an LCA consists of four phases (Fig. 1):

- Goal and scope definition phase, where the final goal of the LCA is stated and the central assumptions and choices in the assessment are identified.
- LCI (Life Cycle Inventory) phase, where input and output flows of matter and energy are quantified for the investigated process.
- LCIA (Life Cycle Impact Assessment) phase, where input and output flow data that have been collected and reported in the inventory are translated into indicators that reflect the pressure on environment and human health as well as the potential or actual resource scarcity.
- Interpretation phase, where the results of the LCIA are interpreted in accordance with the goal of the study to answer questions posed in the goal definition.

In this study, LCA was used to assess the environmental costs and impacts of a thermal power plant generating bioenergy from wood-biomass. The recipe midpoint method was chosen among LCA methods. All LCA indicators were referred to one unit of delivered exergy (functional unit) by the plant in 2011 (Cavalese 1) and in 2015 (Cavalese 2).

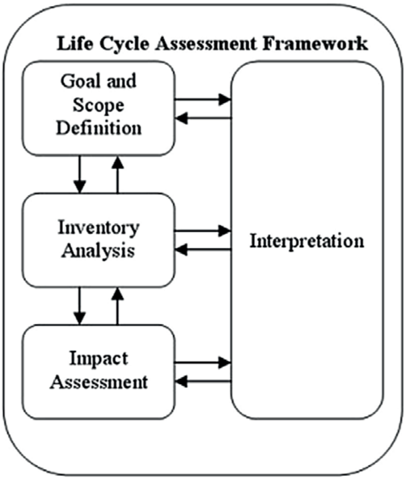

Figure 1. LCA framework

3. Results and discussion

Table 1 shows the total contribution of the thermal power plant in the year 2011 and 2015 to selected impact categories. The contribution to climate change was 3.54E06 and 4.45E06 kg CO_{2eq} for the year 2011 and 2015. The fossil depletion resulted 1.24E06 and 1.68E06 kg oil-Eq for the year 2011 and 2015. These are extensive indicators related to the production of the thermal power plant thus not allowing comparison between the two years.

Table 1. Total contribution of the thermal power plant to selected impact categories.

Impact category	Unit	Cavalese 1	Cavalese 2
Climate change	kg CO2-Eq	3.54E+06	4.45E+06
Fossil depletion	kg oil-Eq	1.24E+06	1.68E+06
Freshwater ecotoxicity	kg 1,4-DCB-Eq	3.02E+04	4.94E+04
Human toxicity	kg 1,4-DCB-Eq	8.09E+05	1.20E+06
Photochemical oxidant formation	kg NMVOC	3.12E+04	4.87E+04
Terrestrial acidification	kg SO2-Eq	1.87E+04	2.87E+04
Water depletion	m3	3.95E+03	5.26E+03

Table 2 shows the contribution of the thermal power plant in the year 2011 and 2015 to selected impact categories per kWh of delivered exergy. The contribution to climate change was 0.30 and 0.26 kg CO_{2eq} per functional unit for the year 2011 and 2015 while the contribution to fossil depletion resulted 0.10 and 0.09 kg oil-Eq per functional unit. Results show that the modifications applied to the plant for increasing bioenergy production also improve the environmental performance. The amount of CO2-eq emissions calculated for the investigated thermal plant (0.26-0.30 kg kWh-1, Table 2) was lower than the CO2 release characterizing fossil fuel-based power plants (ranking from 1.3 g CO2 kWh-1 of a lignite power plant to 0.380 kgCO2 kWh-1 of a natural gas power plant). The calculated value would be even lower if the capability of the local forest ecosystem to offset the CO2 emissions was considered.

Table 2. Contribution of the thermal power plant to selected impact categories referred to the functional unit.

Impact category	Unit	Cavalese 1	Cavalese 2
Climate change	kg CO2-Eq	0.3027	0.2605
Fossil depletion	kg oil-Eq	0.1058	0.0984
Freshwater ecotoxicity	kg 1,4-DCB-Eq	0.0026	0.0029
Human toxicity	kg 1,4-DCB-Eq	0.0691	0.0699
Photochemical oxidant formation	kg NMVOC	0.0027	0.0028
Terrestrial acidification	kg SO2-Eq	0.0016	0.0017
Water depletion	m3	0.0003	0.0003

4. Concluding remarks

LCA implemented in this study allowed the calculation of a large set of indicators to assess the environmental performance and sustainability of the thermal power plant. The use of local wood biomass from forestry and wood industry resulted a desirable option for recycling wood residues while supporting bioenergy production. The use of wood residues to power bioenergy plants has the potential to reduce the fossil fuel supply and related emissions. Finally, the study showed that the modifications applied to the plant for increasing heat and electricity production also improve the environmental performance of the system.

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Sustainability through stakeholder learning: participatory backcasting for the heating sector

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Abstract

Transitions towards sustainability in the heating sector are both very important and highly challenging. Barriers for the required changes include the path dependence of technical infrastructures and networks of actors; required sunk costs; need to ensure continual and reliable heat supply. Changes towards sustainability in infrastructural sectors require long-term orientation, consideration of alternative solutions, shift towards participatory governance (Frantzeskaki and Loorbach, 2010), as well as more reflexive and participatory planning approaches (Truffer et al., 2010). Therefore, knowledge, skills and capacities of the actors involved in planning and decision-making in the heating sector play a crucial role in enabling sustainability transitions.

Participatory backcasting (PB) is a normative approach for participatory strategic planning, which is characterised by involvement of broad range of stakeholders in order to include various knowledge and expertise, facilitate mutual learning, and achieve co-ownership and co-responsibility, and commitment towards agreed decisions (Quist et al., 2011; Quist and Vergragt, 2006). However, in the literature about sustainability transitions and the PB a number of issues related to the nature of learning and organisation of learning processes remains underdeveloped (e.g. van de Kerkhof and Wieczorek, 2005).

This study advances the understanding of learning in participatory strategic planning processes by analysing 1) competences that can be developed through a PB process; 2) whether the learning can be achieved both on the level of individuals, directly involved in a participatory process, and on the level of related organisations; 3) whether the multiplier effect can be achieved and what are the loops of learning in PB processes. The empirical evidences for the analysis have been collected through two PB-based projects in the heating sectors – the first one was implemented in Bila Tserkva, Ukraine, and the second one in Niš, Serbia. The theory applied in the study covers conceptualisations of individual and organisational learning developed in sustainability transitions and organisational change management towards sustainability.

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The process of integrated energetic and environmental audit on historic buildings

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Abstract

The analysis of energetic and environmental behavior of historic buildings is a complex issue, which requires the consideration of various disciplines, from restoration to energy. It also entails an integrated method of diagnosis, simulations and use of specific instruments (E. Lucchi, 2010). For this type of application, it's necessary to understand that all the analyses are applied for the improvement and not for the adaptation to standards. Improvement means the use of a suitable device according to an appropriate architectural and environmental integration; adaptation however, means the complete alteration of the building to adapt it to legislation and necessities. (L. De Santoli, 2014).

The research proposes an integrated method to identify inefficiencies and to define the most appropriate retrofit measures for diagnosis and energetic simulations of the historic buildings, also considering the environmental aspects and the sustainability of buildings.

This method covers everything from the historic analyses to the energy audit, which includes the examination of real uses and internal necessities as well as the environmental monitoring. At the same time it strives to balance the energy and environmental improvement required and the conservation of cultural heritage (E. Lucchi, 2016).

1. Introduction

Historic buildings represent the cultural identity of European countries, characterizing many cities and giving continuity to the past: at the moment, in Italy, 28 museums are pre-XII century, 483 were built between XII and XVI century and 544 between XVII and XIX century (L. De Santoli, 2014). Energy retrofitting is an effective strategy to preserve our cultural heritage, reducing operation costs and improving comfort (F. Roberti, 2015). Unfortunately the assessment of energy and environmental behavior of this kind of building is a complex issue, which requires interdisciplinary approaches, dedicated diagnostic procedures and simulation tools (E. Lucchi, 2010). It's also necessary to understand that all the analyses are applied for the improvement and not for the adaptation to standards. Improvement means the use of a suitable device according to an appropriate architectural and environmental integration; adaptation however, means the complete alteration of the building to adapt it to meet legal standard. This means that the energy efficiency isn't a requalification process which works against the conservation necessities, it is also an instrument of protection (L. De Santoli, 2014).

The adaptation of energy and environmental diagnosis and simulations represents the correct procedure to identify inefficiencies and wastefulness and to define the most appropriate retrofit measures. The general scheme for the process of energy diagnosis is defined in the UNI CEI EN 16247, but the application for historic buildings is more complex. Indeed, there are a lot of obstacles like the lack of plans or the impossibility of founding materials and stratigraphy of construction. For these reasons, the discrepancy between simulated and monitored data could be high due to the large uncertainties of the input data used in the model (F. Roberti, 2014).

In this context, another type of methodology could be considered: consisting not in a new energy auditing procedure, but rather in a new and more modern interpretation of the classical methodology. Its name is Green Energy Audit and it integrates two strategic elements, energy and environment, by mixing the energy audit and LEED methodologies. This synergy achieves a green retrofit for buildings, the construction of buildings, and so future cities, more sustainable (Giuliano Dall'O', 2012).

The paper consists on the proposal for a process of an integrated energetic and environmental audit. It considers the issues inside the analyses of historic buildings and the concepts of sustainability and green retrofit, through the examination and deconstruction of different approaches in standards and legislations, the Green Energy Audit and case studies of energy audits of historic buildings.

1.1. Standard process

In Italy, the legislation about energy diagnosis was introduced by the Directive 2006/32/EC and modified by the Directive 2012/27/EU, that made this procedure for all requalification interventions as a mandatory requirement. In contrast, the intervention of historic buildings are considered voluntary: in this case there is a lack of complete and clear guidelines and standard regulations (Dall'O, 2012). The general procedure of energy diagnosis was introduced with the UNI CEI EN 16247 that defines energy audits like a "systematic inspection and analysis of energy use and energy consumption of a site, building, system or organisation with the objective of identifying energy flows and the potential for energy efficiency improvements and reporting them". This European Standard is composed in five parts: general requirements, buildings, process, transportation and finally, competence of energy auditors. Following the properties of the general energy audit process are defined:

- Appropriate: suitable to the agreed scope, aims and thoroughness;
- Complete: in order to define the audited object and the organisation;
- Representative: in order to collect reliable and relevant data;
- Traceable: in order to trace the origin and processing of data;
- Useful: in order to include a cost effectiveness analysis of the energy saving opportunities identified;
- Verifiable: in order to allow the organisation to monitor the achievement of the targets of implemented energy efficiency improvement opportunities.

The elements of the energy audit process, described in UNI CEI EN 16247 part 1 and 2, are:

- Preliminary contact, all parties/organizations and their role in ownership are identified, the scope of the audit, the timescale, the level of definition (if it is for only an inspection or for a detailed analyses);
- Start-up meeting, the areas and the level of occupancy are defined;
- Collecting data, in function of the definition level of the audit, all the information is collected about energy consumption, values to be used like indicators,

existing design, operation and maintenance documents, energy using equipment; in this element, in addition, the data is analysed and adjustment factors are established or plan further data collection;
- Field work, the site is inspected against the data received and all the technical systems are checked;
- Analysis, the existing opportunities are established; in this phase the energy performance indicators are also identified;
- Report, what is relevant to both technical and executive personnel is targeted;
- Final meeting, the results are presented and explained.

1.2. Green Energy Audit process

The Green Energy Audit maintains the basic features of the energy audit but it is aimed at a far more important goal: improving the overall sustainability of the building. The main difference with the general energy audit's process is that in the "analysis" section, only sustainability retrofits are evaluated. This methodology is also strictly related to the retrocommissioning process and the LEED protocols. The first is a systematic method for investigating how and why an existing building's systems are operated and maintained, and identifying an operative procedure to improve overall building performance. The second one represents the world's most used certification system, developed by the U.S. Green Building Council (USGBC). It aims to use resources efficiently by using less energy and water, reducing greenhouse gas emission and transportation pollution, and selecting products to reduce the effects of their harmful components. The components inside this certification related to measures affecting Green Energy Audits are accounting for 60% (Dall'O', 2012).

1.3. Experiences of energy diagnosis on historic buildings

Various experiences and studies of energetic audits in historic buildings have been collected in recent years: some investigated the importance of value conservation and the correct choice of retrofit opportunities with mathematical calculations; others analysed how much data should be collected during the survey and how to obtain it. The general process for the majority of these experiences can be resumed in:

- Collecting historic, functional and geometric data and other analyses with specific instruments for the investigation of artefact conservation or degradation;
- Thermodynamic modelling and its comparison with benchmarks;
- Identification of energy retrofit opportunities and the control of intervention compatibility with the historic importance of the building;
- Intervention planning;
- Monitoring of the building *post-operam*.

2. Proposal of process for historic buildings

The research aims to define a process of energetic diagnosis for historic buildings, integrated with concepts such as environment and sustainability. The proposed methodology, illustrated in figure 1, starts from the process previously mentioned, adding specification of:

- collecting data: in historic buildings it is vitally important to dedicate a long period of time to researching historic data as well as planning field surveys to investigate stratigraphies; in new construction all the project and decisions are registered, but in this case it's necessary to examine all the building properties.
- energy opportunities: the retrofit and the retrocommissioning are present in this section because they pursue sustainable and green objectives; in this manner, it is possible to inspect building's systems and operative procedure; in addition, it will be easier to achieve an energy certification system.
- analysis: the consideration of the cost-benefits isn't sufficient for historic buildings because it's necessary to examine the compatibility of interventions. As previously mentioned, in this case all the analyses are applied for the improvement and not for the adaptation to standards.

Moreover, the phase of monitoring the energy values *post-operam* has joined at the end of the process. The effects of energy requalification's intervention will be introduced in the scheme where the auditor collects indicators such as energy consumption for heating, cooling or domestic hot water.

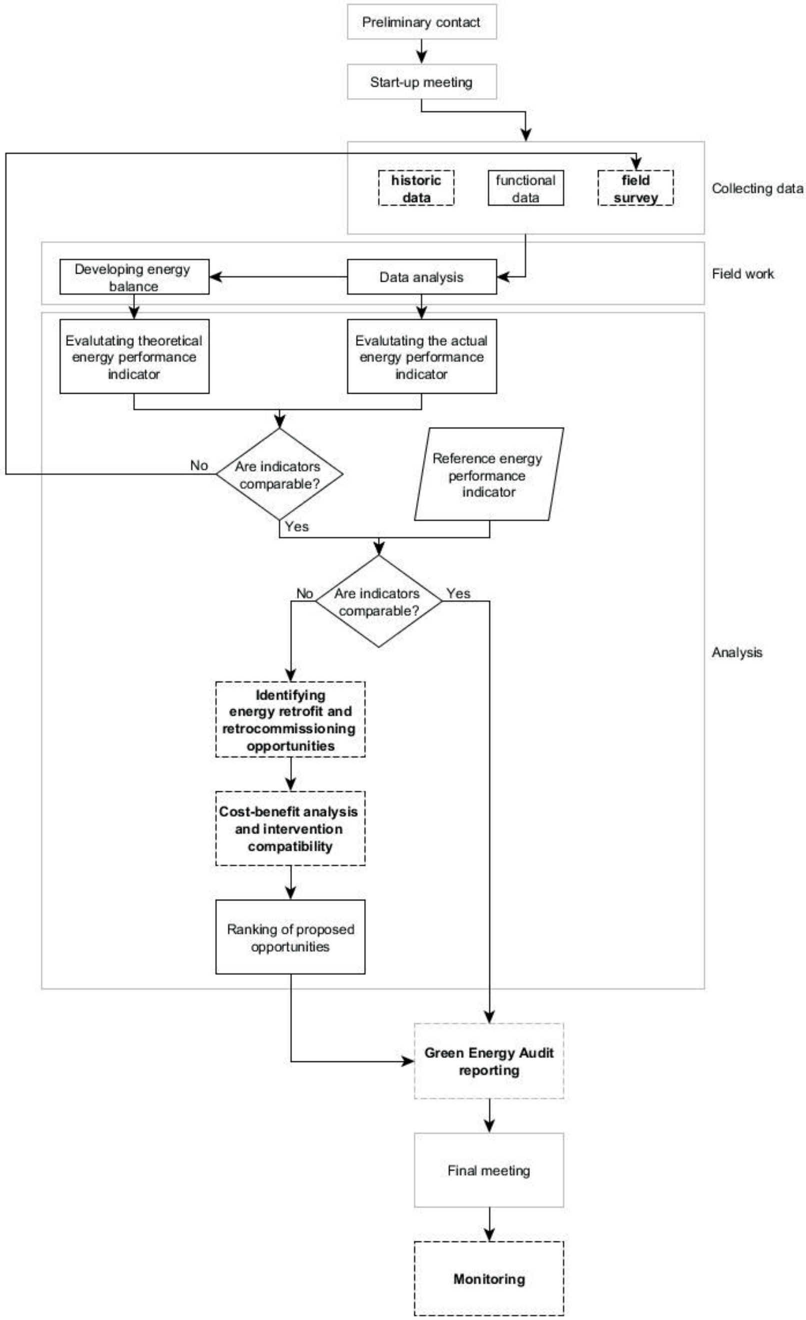

Fig. 1: the proposal process of energetic and environmental audit on historic building; grey square for elements described in UNI CEI EN 16247. The dashed lines represent the new elements introduced in

the scheme and concern the introducing at the end of monitoring and the modification of: collecting data part, identification of energy opportunities, the cost-benefit analysis, the final report.

3. Conclusions

This process proposes the application of the standard workflow adapted to historic buildings. It also considers a complex issue which is the need of interdisciplinary approaches, from diagnostic procedures and simulation tools to conservation and restoration. This research also includes the aim of introducing green and sustainable concepts chosen from a range of possible interventions: the use of only energy retrofit and retrocommissioning opportunities can achieve the objective whilst following international protocols as well as reduce the consumption of fossil fuel.

The system proposed in this paper is theoretical, but it is currently been tested on an historic building, the Ca' Rezzonico (18th Century museum situated in central Venice which is the subject of the certification process in LEED O+M). This integrated method, which identifies inefficiencies and defines the most appropriate retrofit measures for a green diagnosis and energetic simulations, is contributing to do the selection process inside the LEED protocol. Moreover, it is supporting the staff to examine in the correct way the actual energy performance and to analyse possible interventions to improve the energy statement of the building.

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Standards

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Assessing ecosystem services in the Egadi Islands Marine Protected Area: an energy perspective

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Abstract

Natural capital stocks and the ecosystem services (ES) they underpin are essential to human societies and well-being. With the ever-increasing human population and related needs, humans are exploiting Earth's resources at unsustainable rates, perturbing the structure and eroding the diversity of ecosystems, and eventually compromising the ability of nature to continue providing the flow of services on which human life relies.

Marine and coastal ecosystems are among the most productive environments in the world, offering a wide variety of services (e.g., seafood provision, carbon sequestration, cultural and spiritual benefits). Their delivery entails environmental costs and impacts that should be taken into account by means of environmental accounting methods.

In this study, the emergy accounting method was used to assess the environmental costs for the generation of ES in the Egadi Islands Marine Protected Area (EI-MPA) located in Sicily, southern Italy. Data on the main activities (fishing, diving, bathing and boating) occurring in the study area were gathered through structured surveys. Mass, energy and money flows supporting the investigated activities were accounted for, converted into emergy units, and eventually summed into a total amount of emergy used for the generation of the ES in the EI-MPA system.

Investigation of rebound effect in energy consumption of megacities

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Abstract

In the last decades, megacities, i.e. urban agglomerations counting more than 10 million inhabitants, have raised both in number and in importance worldwide. Considered as the future paradigm of urban evolution in emerging countries, their urban metabolism has been recently assessed by Kennedy (Kennedy et al, 2015), revealing how their impact under the point of view of energy and resource management will pose important sustainability challenges for the future. In particular, the energy dimension is one of the most critical, as showed by Facchini (Facchini et al., 2017) who focused on energy metabolism.

Following this work, the aim of this paper is to investigate the dynamics that link the energy growth with respect to population growth in terms of rebound effect (Berkhout et al, 2000, Ruzzenenti and Basosi, 2008, and 2009.). In fact, especially in the megacities located in fast developing and emerging countries energy consumption grew in the period 2001-2010 at rates that are in some case 10 times or higher with respect to population. By example, in Rio de Janeiro a population growth of 10% produced an increase of electricity consumption of about 100%, with a growth rate of about 10 times larger. Such rates are also found in the other megacities of the Latin American region as well as in India and Asia.

We also show that the above-mentioned effect is also reflected in GDP and mobile energy consumption, but does not significantly appear in the case of water consumption and solid waste production (where growth rates of about 5 times are rarely observed), suggesting that moving to more efficient forms of energy (climbing the energy ladder) triggers both economic development and energy consumption at rates that are much greater with respect to population growth. Our preliminary results suggest to policy and decision makers from municipalities and utilities an approach to infrastructure development that keeps into account consumption according to a superlinear scaling pointed out in the paper.

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Experimental assessment of impact energy in oblique and asymmetric water entry

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Abstract

The motion of marine vessels during navigation is deeply influenced by the asymmetric water entry of the hull. In real-cruise conditions, the hydrodynamic loading due to the impact is completely different from that caused by symmetric water entry. For this reason, the study of real-cruise water entry has a pivotal role in many fields of marine engineering.

The aim of this work is to examine in depth the effects of heel and velocity angles on the energy exchange during water entry. Impact tests are performed by means of a rigid wedge, free falling from a height of 50 cm, changing the values of impact direction (α angle) and the heel angle (θ angle). We compute the amount of energy imparted to the fluid, including the pile-up regions and the water jets, by using planar particle image velocimetry (PIV). The results highlight the combined effects of both impact direction and heel angle on the energy transferred from the structure to the fluid, thus highlighting the versatility of PIV technique and providing a set of reference data for future studies and design optimization.

1. Introduction

The study of the impulsive loading resulting from hull water entry during standard cruise is the object of a large number of experimental and theoretical studies.

Since the early 1930’s [1, 2], remarkable efforts have been devoted to the dissection of impact dynamics connected to hull slamming, focusing both on the solid structure and the fluid behavior. While these experimental and numerical studies have greatly contributed to gain a refined understanding of water entry, a thorough understanding of the physics underpinning water entry is far from accomplished. Specifically, there is a lack of experimental data on the impact dynamics and fluid flow related to purely oblique or oblique and asymmetric water entries. In the large part of the experimental and numerical works, in fact, the body is assumed to fall along a perfectly vertical trajectory, which is a remarkably strong hypothesis, compared to real-cruise conditions [3, 4, 5].

The main goal of this work is to deepen into the energy exchanged between the fluid and the wedge-shape specimen during oblique and asymmetric water entries. To this aim, we perform planar PIV at the mid-span of wedge to study energy transfer during the impact, by adopting the methodology proposed in [5, 6, 7], extended to account for the asymmetry in water entry problems. We compare the data obtained through the planar PIV to those provided by a standard measurement chain, realized by means of a position sensor, a ±3g capacitive accelerometer and a ±200g piezoelectric accelerometer. The two accelerometers are used to measure with high accuracy free fall and impact acceleration respectively.

Experimental tests are conducted employing a rigid wedge, which impacts the free surface from a height of 0.5 m. The heel and velocity angles are systematically varied and their effect on the overall energy exchange is evaluated.

2. Materials and method

2.1 Experimental setup

The experimental test bench is composed of a water tank, made in stainless steel with an internal volume of *1500x1850x700 mm³*. Two optical access made of Lexan®, allow to acquire images by means of a high speed camera. An adjustable guiding rail made with a *45x45 mm²* t-slotted aluminum frame allows to vary the velocity impact direction. An aluminum carriage system, assembled with 4 ball bearings, is used to perform the free fall impact experiments.The specimen is a rectangular based wedge with length of *190 mm*, width of *200 mm*, height of *80 mm and a keel angle of 107°*. The wedge is attached to sliding cart through an aluminum arm equipped with a planar junction, which allows to fix θ.
Besides the double-sided acquisitions, it is possible to perform different kinds of experiments, without the need of changing the experimental setup. One of the most remarkable aspects of our experimental apparatus is the capability of performing both free-fall and controlled impacts. The latter are performed by means of a linear electric motor.

2.2 Data acquisition systems

To measure the wedge displacement, the rail is equipped with SoftPot SP-L-0750-203-3%-ST resistive position sensor, made by Spectra Symbol, actuated by a wiper stud mounted on the carriage. Acceleration of specimen along the rail is measured by means of two accelerometers: a capacitive accelerometer model ADXL335 with ±*3g* measurement range and a piezoceramic accelerometer model 805M1 manufactured by Measurement Specialties™ with dynamic range of ±*200g*. Former measures the free fall acceleration, latter estimates the acceleration during the impact. Positon and acceleration data are collected through a National Instruments DAQ board NI USB-6431 DAQ board at *10 kHz* sampling frequency, using an ad-hoc Virtual Instruments developed in LabView environment.

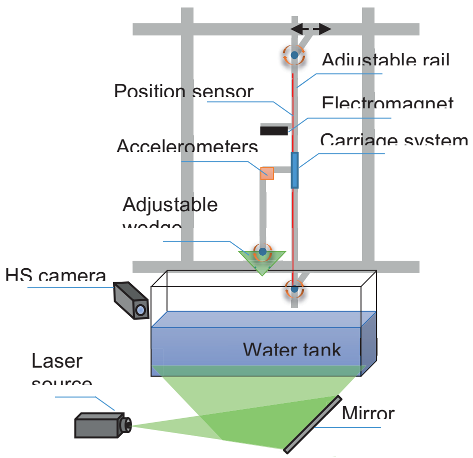


Fig. 1: Simplified sketch of experimental test bench

The time-resolved planar PIV system includes Raypower 5000 laser source and a NAC MEMRECAM HX-5 high speed camera. Laser source emits a laser sheet reflected by a mirror arranged on the bottom of water tank at mid-span of wedge, to illuminate polyamide seeding particles used as tracers. The camera acquires images with a size of *2048x520 pixel*^{2} at *12 bit* grey scale and *6kfps*. We analyze 150 frames, corresponding to an acquisition time of *25 ms,* during the water entry. The initial time instant of analysis $t_0 = 0$ corresponds to the first contact of the keel with free water surface.

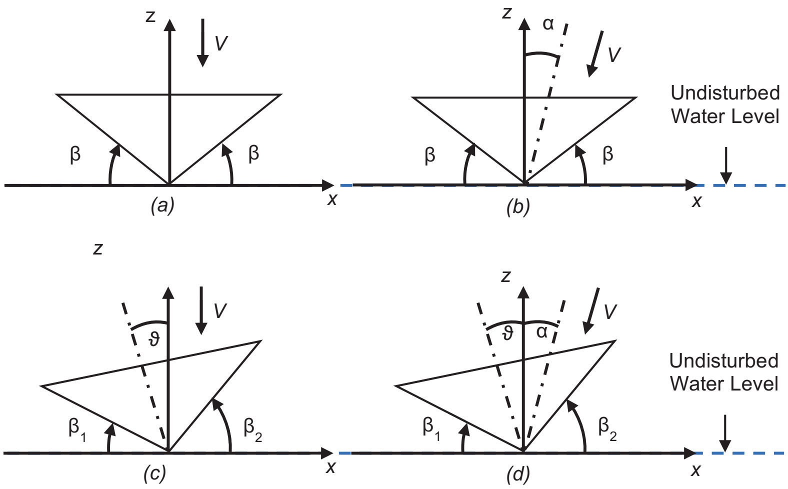


Fig. 2: Experimental Conditions: (a) Vertical Symmetric Impact ($\alpha = 0$; $\vartheta = 0$; $\beta_1 = \beta_2 = \beta$); (b) Oblique Symmetric Impact ($\alpha > 0$; $\vartheta = 0$; $\beta_1 = \beta_2 = \beta$); (c) Asymmetric Impact ($\alpha = 0$; $\vartheta > 0$; $\beta_1 < \beta_2 > \beta$); (d) Oblique Asymmetric Impact ($\alpha = 0$; $\vartheta = 0$; $\beta_1 = \beta_2 = \beta$)

2.3 Data analysis

PIV frames are analyzed by means of GUI PIVLab, an open source time-resolved digital particle image velocimetry tool for Matlab [8]. For each combination of α and θ angles the PIV images acquired by the camera are manually masked for the first trial and the same mask is used for the other four trials. The manual masking is performed using a custom built Matlab routine based on the roipoli function, as described in [10].

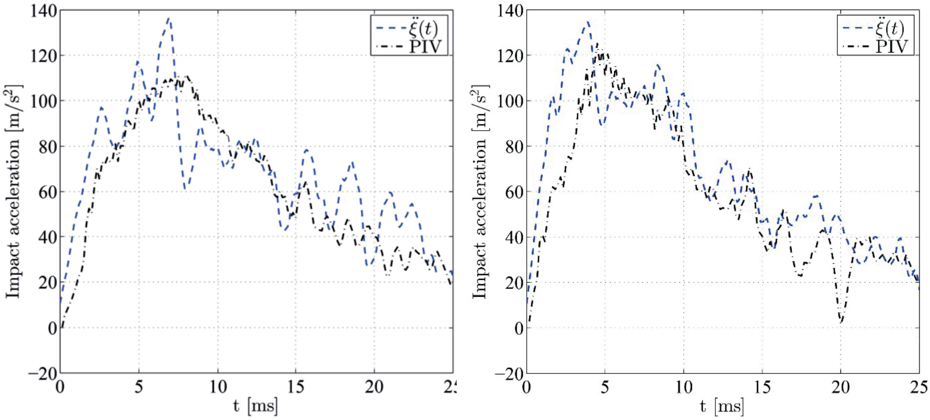
PIV data analysis is performed using the FFT-based cross correlation algorithm of PIVLab, accounting for the displacement of the interrogation area between two consecutive frames calculated using the cross correlation method. The analysis is performed setting three subsequent interrogation area dimensions of 64x64, 32x32 and 16x16 pixel^2 respectively for pass 1, pass 2 and pass 3. The sub-pixel estimation is then performed through the Gauss 3x2 method.

3. Results and discussion

In this section, we evaluate the combined effect of oblique and asymmetric impacts on the water entry of our specimen. In order to evaluate the impact dynamics, we evaluate the acceleration during the impact and the energy exchange between the fluid and structure, including pile up and water jet region, considering the effects of α and ϑ angles. Data are obtained through particle image velocimetry (PIV) and by using the ±200g piezoelectric accelerometer. As expected, results highlight the strong influence of geometric and kinematic asymmetries on energy exchanged between fluid and structure during water entry.

3.1 Comparison between the accelerations obtained with PIV and the accelerometers

Impact acceleration in time is calculated from PIV by integrating pressure values along wedge wetted bounds. Results are compared with ±200g accelerometer data. Acceleration values are employed to compute the impact force, multiplying the impact acceleration by the impacting dry mass.
To test the accuracy of our methodologies, we have compared PIV and direct measurement results. Results presented in in Figures 3 (a) and (b), demonstrate the very good agreement between direct measurements and PIV-based results. For sake of brevity, we report two cases representative respectively of symmetric (α = 0°, ϑ = 0°) and oblique asymmetric impacts (α = 10° and ϑ = 10°).



(a) *(b)*

Fig. 3: Average time-histories of impact vertical acceleration acquired through PIV and ±200g piezoelectric accelerometer for: (a) α = 0° and ϑ = 0°, (b) α = 10° and ϑ = 10°.

3.2 Computation of impact energy

The energy imparted to the fluid during water entry is computed according to the method proposed by [6, 7] and implemented in [10]. The energy of wedge per unit length is calculate as follows:

$$E_{wedge}(t) = \frac{1}{2} M \dot{\xi}^2(t) - Mg\xi(t) \qquad (1)$$

ξ and $\dot{\xi}$ are the vertical components of wedge displacement and wedge velocity during water entry respectively. Equation (2) allows computation of the energy per unit length released to the fluid during the impact, neglecting damping

$$E_{fluid}(t) = E_{wedge}(0) - E_{wedge}(t) \quad (2)$$

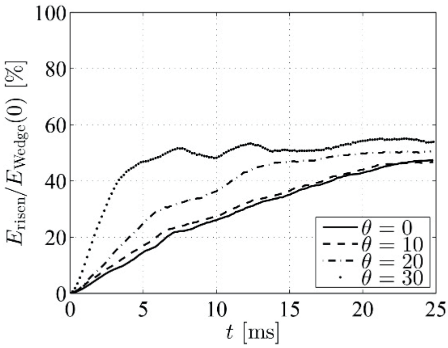
The energy per unit length imparted to the fluid is composed as follows:

$$E_{fluid}(t) = E_{bulk}(0) + E_{risen}(t) \qquad (3)$$

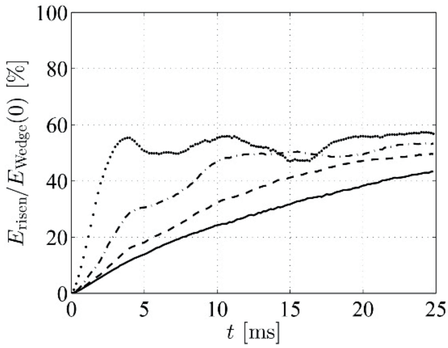
The evolution of E_{risen} is calculated as a fraction of the wedge energy at the time instant $t_0 = 0$, for all experimental conditions, results are averaged across five trials, see Fig.4. We observe that the energy released to risen fluid, including pile-up and water jet region, increase and saturates in time-span of experiments. The maximum value of ratio between $E_{risen}(t)$ and $_{Ewedge}(0)$ is around 40 – 60 %. The strong dependence of peak value on θ is evident, on the other hand α slightly influences the energy imparted to the risen fluid.
In order to examine in depth the influence of α and θ on the energy exchanged during the impact, we report in Fig.5 the amount of energy transferred to the fluid bulk as a fraction of total energy imparted to the fluid. The peak value of E_{bulk} decreases for higher values of heel angle. The maximium value reached from E_{bulk} is bounded between 25 to 50% of E_{fluid}.

4. Conclusions

In this work, we have experimentally analyzed the influence of heel and velocity angles on the energy released to the fluid during water entry, by adopting a PIV-based methodology. Our approach has proven capable of evaluating the acceleration during the impact and the total amount of energy imparted to the fluid around the wedge during water entry for different values of velocity and heel angles. The results highlight the paramount importance of oblique asymmetric impacts analysis to fully characterize real-cruise conditions. The data-set obtained through our experimental measures provides a valid support for the design of novel vessels and for the validation of numerical and analytical models for the dissection of fluid structure interaction connected to water impact phenomena.



(a)



(b)

Fig. 4: Average of energy imparted to the risen water E_{risen} calculated as a percentage of initial wedge energy $E_{wedge}(0)$ for: (a) α = 0°, (b) α = 10°. (Figures adapted from [10])

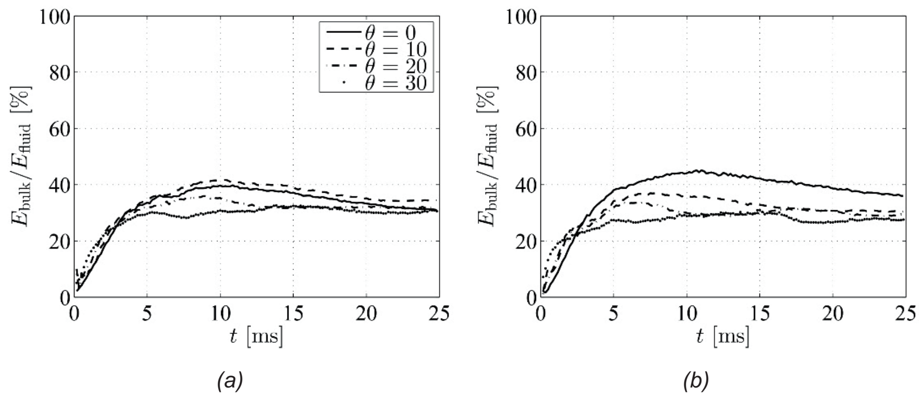


Fig. 5: Average of energy imparted to the fluid bulk $E_{bulk}(t)$ calculated as a percentage of the total energy transferred to the fluid $E_{fluid}(t)$ for: (a) α = 0°, (b) α = 10°. (Figures adapted from [10])

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Social innovation for energy sufficiency – methods, results and lessons learnt in the EUFORIE project

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Abstract

For a long time now energy savings through energy efficiency measures are partly compensated particularly by income growth but also rebound effects. This paper shall provide the floor for broader and more informed debates on the potentials sufficiency considerations can contribute to the overall reduction of energy consumption of private households.

1 Introduction

In the last four decades, energy efficiency increased significantly in OECD countries. However, only recently, total energy consumption started to decrease a little, and much more slowly than energy efficiency potentials would suggest. Efficiency improvements are considered to provide reductions in energy use without corresponding inconvenience or loss of amenity. In this perception, efficiency might best be thought of as a measure of *relative* consumption. Furthermore, efficiency is usually measured for a specific technical system, and not for broader human behavioural patterns. As a result there relative improvements dominate the debate, while the distance to target – the issue of concern to environmental policy – is not the decisive criterion in technology development, marketing and labelling.

Efficiency tends to reap the low hanging fruits, but less of them than frequently expected due to rebound effects on the micro- and the macro-level. Thus it is not enough and sufficiency, also referred to as enoughness or strong sustainable consumption must accompany it and the just as indispensable policy initiatives: neither neglecting consumer involvement, nor delegating responsibility to them offers solutions for the sustainability challenges. This is as true for domestic energy consumption as it is for any other consumption domain (Lorek 2010; Lorek, Spangenberg 2014). Consequently, Europe and (all) other countries also need to look beyond efficiency improvements towards how we can reduce absolute energy consumption, and to seriously discuss and understand what drives consumption. Thus energy sufficiency has gained new attention as a way to limit and reduce total energy consumption of a household or a country: we need a profound discussion on sufficiency and limits. Housing as one of three dominating domains of household resource consumption (Spangenberg, Lorek 2002) is a suitable starting point for such a debate.

2 Methodology

This paper is based on intensive literature review in consumer/consumption, ecological economics, sustainability and other journals. A rather general scan covered 56 journals on energy, sustainability or consumption issues. While in the majority of journals sufficiency does not appear at all, few others concentrate on self-sufficiency in a sense of voluntary simplicity. This however, is not what this project intends to identify. Instead it develops sufficiency in a broader, not least political context and therefore searches framing conditions which support sufficiency thinking and behavior beyond individual sacrifice.

Sufficiency considerations in such a sense were found in more hidden ways in various researches recognizing the limits of efficiency approaches – mainly in energy, environment and housing related journals. The most concrete and developed ideas, however, still seem to be in a project phase and have not made their way to peer reviewed academic journals. Therefore in broad parts the paper is based on exemplary projects, mainly found in a German, Swedish and Swiss context. The selection of the final collection of ideas and instrument presented here were steered through exchange and interviews with scholars and practitioners working in the field of e.g. energy efficiency, energy consultancy and 'beyond GDP' research and initiatives.

3 Energy Sufficiency at homes

The existing trend in housing is a continuously growing floor space per capita. Forecasts expect a further increase from about 20 m² in 1960 via currently 45 m² to more than 50 m² per person in the coming decades. Obviously, more floor space needs more energy for space heating and cooling, ventilation, and lighting (except for the marginal number of zero energy buildings). It also allows the household to operate more and or bigger appliances, all of which increase energy consumption. Whether this is an indication of peoples willingness to consume (Røpke, 1999) or if they are locked in (Sanne, 2002) is an ongoing debate. In any case, instruments for limiting average dwelling floor area per person will have to be an important part of any energy sufficiency policy package as they address one important driver of energy consumption and non-sufficiency (Thomas, Brischke, Thema, & Kopatz, 2015).

Even in efficient buildings running on renewable energy and equipped with best class appliances a moderate sufficient lifestyle can result in an additional reduction of 45% of greenhouse gas emissions. Thus sufficiency concepts may become the wild card to ensure that climate targets can still be reached. Previous studies highlight three main measures of successful sufficiency gains (1) reducing the per capita living area (calculation basis from 60m² to 40m²), (2) a moderate change in user behaviour in the use phase of household electric and electronics and (3) a change in the mobility modal split (Pfäffli, 2012; Steffen & Fuchs, 2015).

A helpful perspective to overcome the tension between upscaling norms and factual needs and to recognise the surplus of the sufficiency approach regarding domestic energy consumption is offered by Ellsworth-Krebs and colleagues (Ellsworth-Krebs, Reid, & Hunter, 2015). They recommend looking from a perspective of home and not purely the house.

The house approach is based on a traditional development prioritising engineering, technology and techno-economic thinking. Its dominant focus is on thermal comfort around a suggested optimal temperature of 21◦C (Fanger, 1970). Ellsworth-Krebs and colleagues point towards the home approach which looks beyond the physical/material object and calls to recognise alternative discourse which recognises that comfort is constructed and cannot be objectively defined. The intervention strategy therefore lies more towards the social end of the socio-technical axe.

In addition the home approach also delivers its potential when considering aspects beyond the house. Energy effects of homes include more than just the own flat but the neighbourhood (Knüsel, 2013). Questions to raise for the promotion of sufficient lifestyles reach from the fulfilment of further basic needs: Is the provisioning of daily needs nearby possible? Do people have easy access to (public) mobility options? Is recreation possible nearby? As mobility is the second determinant of household resource consumption (after housing and with nutrition, Spangenberg, Lorek 2002) is focus is not incidental but necessary. Other questions refer to social needs: Are their places to meet people? Can I receive guests? etc.

Thus concepts for sufficient living necessarily consider the location of the homes. Interestingly most projects striving for sufficient living conditions are found in urban areas not on the country side as false assumption about sufficiency communities might suggest. They are often located in inner cities where the reduction of transport plays a crucial role. E.g. energy use is avoided when grocery shops are at reach either by foot or bicycle, when public transport is reachable within 500 m from the house and/or car sharing facilities are offered in similar distance.

4 Engaging with stakeholders

5 To achieve sufficiency in homes need a broad variety of different considerations and will need engagement of a many different stakeholders. What ties the bits and pieces together, however, is the aspect of social innovation.

The design role of planners and architects

Architects and designers have the potential to play a crucial role in communicating sufficiency as well as paving the way through practical leadership. So far architecture contribution to ‘a good life’ is mainly perceived in the sense of providing more space (Zarghami, Fatourehchi, & Karamloo, 2017b). However, the self-understanding of architects starts to change from ‘as much as possible builders’ towards ‘space problem solvers’(Steffen, 2014). This holds true for the home in sense of the house as well as of the neighborhood. In the current era of corporate-led urban development and the commercialisation of public space, critical architects, urbanists and citizen groups are exploring strategies and ways to democratise the city. Within these groups there is marked interest in creating and safeguarding urban commons – spaces not primarily defined by their formal ownership but by how citizens use them (Bradley, 2015).

Housing companies and cooperatives

Examples show that communal or private cooperatives as well as private companies already develop interesting approaches towards sufficient homes.

Especially non-profit cooperatives are devoted to support the common good through their statutes already. Gessler and colleagues report from Switzerland, that subsidized flats thorough their occupancy regulations are requiring a specific number of tenants per amount of m². This holds true for existing flats and also limits the tendency to ever larger individual space in new build homes. In this sense, the GAG Immobilien AG Köln for example, an incorporated company, considered to retreat from stock market to be able to build smaller again.

To keep tenant relationship housing association, at least large ones, are in a good position to offer an exchange programme for apartments, e.g. for the widowed seniors. Beside the knowledge where adequate flats are available they also have the possibility to adequately consider the price and ensure that the rental agreement for the new flat is less expensive than the old one (Thomas et al., 2015). Another incentive would be to practically help with moving through offering packing and transport service (Fuhrhop, 2014).

In addition real estate companies can influence mobility patterns, e.g. through providing bicycle facilities or privileged parking space for car sharing (Gessler, Gugerli, & Altenburger, 2013).

Middle actors

Next to planners and the housing companies some crafts professions (e.g. builders, heating installers, plumbers and electricians) play a rather practical role in shaping sufficient or un-sufficient behaviour. Literature perceive them as intermediaries or 'middle-actors' (Parag & Janda, 2014; Wade, Hitchings, & Shipworth, 2016). Builders e.g. are crucial to mediating between consumers and technology, to enabling the physical changes needed, to spread the message of sufficiency behaviour and finally to train the home users how to adopt behaviour to meet carbon-reduction targets. They can improve customer capacity by providing them with efficient infrastructure and explaining to them the importance of their handling to ensure a sufficient use of them.

Municipalities

Municipalities are the administrative units closest to provision of homes to their citizens. Thus they are in a key role to consider sufficiency issues properly. Many initiatives can be and have to be done locally and in co-operation. As they have limited access to hard policy instruments, municipalities need to rely on leading by example and providing a fertile ground for local action – not at least supporting initiatives by other stakeholders (Bangens & Nilsson, 2015).

One area for communities of great importance is to support dwelling exchange or, more general, to take care that enough flats of reduced size – and of lower price – are offered. An information instrument requiring limited effort is a local internet based platform for dwelling exchange. However, as a voluntary approach, it will not be contentious but its effectiveness is might also be limited (Thomas et al., 2015).

Larger impact might come from an obligation to report vacancies to the authorities and or a public register (Thomas et al., 2015). Also rebuilding may help to create required smaller flats. Thomas and colleagues provide examples from some large German cities: In Frankfurt, for example, after years of vacancy a huge office building with 14 floors had been rebuilt and divided in almost 100 apartments.

Sufficiency consultancy as well is an instrument worth considering. Municipalities actually would be a trustable host of such institutions. Beyond a purely digital platform sufficiency consultancy could bring together elderly people interested to move to smaller homes with families or people interested in shared apartments. Well organised such a sufficiency centre (in very large cities even various centres for the different quarters) would have the best chance to ensure people can stay at least in their neighbourhood when they move (Fuhrhop, 2014).

6 Public policies

Last but not least public policies are of vital importance to create the framework conditions for sufficiency thinking and acting. They can target energy consumption directly or indirectly restricting the space on which – residential – energy is consumed. Policy frameworks enabling sufficiency need to create an environment in which products as well as infrastructures can flourish which need much less energy.

6.1 Energy related policies

Clear and direct price signals are one element in this context. Progressive tariffs are one interesting approach here. As examples from Italy (and California) show, they seem to function well in the liberalized electricity markets. Social and energy related political interests seemed to be important functional conditions for the launch and implementation of progressive tariffs in the electricity sector, both in Italy and in California (Dehmel, 2011). A further step could already intervene in the design phase. Also energy using products might be developed under the requirements of progressive efficiency demands. According to such a concept larger TV sets then would have to be more efficient in relation to screen size than smaller ones (Brischke & Spengler, 2011).

6.2 Targeting space

Energy consumption per person is supporting sufficiency approaches in a better way than energy use/m². This could be applied for public loans as well as become main criterion in regulations (in Germany e.g. the Energy Saving Ordinance) or certification schemes (e.g. those developed by the Germany Sustainable Building Council (Mårtensson, 2016; Steffen & Fuchs, 2015).

Policy may support sufficiency approaches e.g. through public architectural competitions or requiring that any such competitions should include guidelines and requirements for less living space per person (Thomas et al., 2015). One obstacle to overcome regarding smaller or even compact housing is the strict building regulations and the requirements of accessibility (Mårtensson, 2016).

An interesting element in the overall picture is to also reconsider urban respectively sub urban development plans. The most radical approach would be to allow the building of new houses only to cities with a growing number of inhabitants. New buildings also in constant or shrinking cities would be still possible this way but only under the condition that area of a similar size is de-sealed. Such a moratorium could generate a new wave of architectural and planning creativity to improve available building stock, not at least for the changing demand of housing opportunities (Kopatz, 2014, 2016). Such a regulation would potentially be the most powerful, but certainly a very contentious instrument. (Kopatz, 2014)A less strict element are tradable permits for soil sealing. From 2012 to 2017 the Federal Environment Agency in Germany experimented with such a concept. The target of 30ha/day was taken as the upper limit for Germany. Free certificates were given to participating cities. The criterion for the allowances were the number of inhabitants of a city (UBA, 2016). In case of new building plans, the corresponding certificates have then to be filed by the planning authorities. As required, they may buy or sell contingents of certificates. This would satisfy the needs of growing cities but also give an incentive to all municipal authorities to limit new build of dwellings (Thomas et al., 2015)

The experiment fruitfully strengthened the development of the inner cities. Spaces between buildings or other unused space was activated in a way that they fully compensated the space avoided at the edge of the cities (UBA, 2016).

An accompanying study on legal issues showed that the permit solution could be integrated in communal building planning rather easily. Accompanying measures helpful on the way would be further planning obligations to steer and restrict settlement area and the further development of monitoring requirements (Bovet, 2017).

6.3 Inducing sufficiency in a circular economy

Finally, the sufficiency aspect in and for homes is also an aspect on the way to a circular economy. So far developing settlement areas seem to be a one way process. To close the circle could be fostered through 'take back' obligations for building. A comparable instrument is established already long out through history in the German mining law where mining areas have to be re-naturalised after the active period. Financial and technological planning for the taking back then would have to be established with the building permission (BMUB, 2016). Also open source approaches could help in a circular economy as they would transparently show construction principles and materials used and thus support more sustainable solutions (Petschow & Peuckert, 2016; Zimmermann, 2016).

7 Conclusion and outlook

So far living in smaller homes is not especially widespread, not even among sustainable housing projects. But if the prerequisites are getting more supportive, it could hopefully spread more (Mårtensson, 2016). What becomes clearer more and more is to construct a giant apartment and call it energy-efficient is not especially sustainable. Reducing the size of individual living space, in combination with shared facilities and user-friendly smart technologies make both environmental and economic sense. The driving force is indeed often economical because land prices are high and people want to live in cities. Quite some examples are under development or carried out already that downsizing is gaining popularity. A further motivation for such project is to learn more about the consequences of building smaller and if it is possible to obtain sufficient quality of accommodation on such small areas. The attention such project receive contribute to raise awareness for the underlying intention of sufficiency.

Sufficiency instruments need to reach far beyond individual decisions. Various groups carry out valuable pioneer work already. In the end however, only political regulatory framing will be able to induce a limit in energy, resource and space consumption per person. (Steffen & Fuchs, 2015). Politics and policies should recognise sufficiency as a field of action instead of referring to individual decisions and lifestyles (Bierwirth & Thomas, 2015).

Creative and structured communication processes help to build trust between planners, designers and architects, municipalities and politics, all other actors and the inhabitants (Bierwirth, 2015).

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Microbial Fuel Cells (MFCs) Remediation Activity of Marine Sediments Sampled at a Dismissed Industrial Site: What Opportunities?

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Abstract

The wellness of our future generations is strictly connected to the environmental health of sea, soil and air. In the past decades, poor attention has been devoted to the impact of human activities on the environment, in many cases, with soil, rivers and sea considered as a sink for human waste. In this work, we present the preliminary results of a remediation experiment carried out by means of Microbial Fuel Cells (MFCs) on six samples of marine sediments collected in the Gulf of Pozzuoli, in Campania Region (Italy). These samples contained a high concentrations of pollutants, due to a steel plant off-shore dumping activity, which has lasted for more than 80 years. Chemical analyses of our samples revealed the presence of all 16 Polycyclic Aromatic Hydrocarbons (PAHs) listed among the "priority pollutants" by the US-Environmental Protection Agency sediments, with concentration ranging from a maximum of 30 ppm (fluoranthene) to 0.21 ppm (acenaphthene). PAHs degradation trend and power production, as well as the potential in-situ application of scaled MFCs are discussed.

1.Introduction

Recently a growing interest was developed by scientific community towards the environmental pollution by PAHs and, more in general, by hydrocarbons and other chemicals spreading in the environment as a consequence of human activities (Nastro R.A. et. al, 2014; Habibul N. et al., 2016). PAHs demonstrated to be deleterious for both human and environmental health (Makkar R.S. et al., 2003; Morris et al., 2007 Nastro R.A., 2014). The main issues related to the widespread pollution of complex organic compounds relies in their bio-accumulation along trophic networks food webs (Makkar R.S. et al., 2003; Nastro et al., 2014). PAHs in water ecosystems tend to accumulate in sediments, persisting in the environment, even for decades [WHO, 1998]. Among other remediation processes, bioremediation is considered more effective, affordable, safe and less soil disturbing than chemical and physical approaches. In the last years, biological remediation processes proved their efficiency in the removal of both heavy metals and hydrocarbons, with encouraging results. Particularly interesting is the recent extension of the use of fuel cells in bioremediation problems, which has produced the Microbial Fuel Cells (MFCs) and, more in general, the Bioelectrochemical Systems (BESs).

1.1 Microbial Fuel Cells (MFCs)

In recent years, MFCs technology showed significant potentialities in the remediation of sediments polluted with hydrocarbons and heavy metals, with partial energy recovery in form of electric power production (Abbas et al., 2017, Morris et al, 2008, Chandrasekhar et al., 2015). MFCs, like other BESs, can take advantage of biological capacities of microbes, enzymes and plants in catalazying electrochemical reactions. In these “biologically-based-fuel-cells”, the organic compounds contained in different substrates are used as fuel: landfill leachate, municipal and agro-industrial wastewaters, sediments, solid organic waste, among the others, (Jannelli et al. 2017). In a MFC, bacteria use organic compounds as source of energy for their metabolism, producing protons, electrons and catabolites. Then, exoelectrogenic bacteria exchange electrons with the anode in anaerobic/anoxic conditions: this transfer can be mediated or not by carriers (like phenazines, quinolones, etc.), accordingly to the physiology of biofilm-forming-bacteria and to the terminal electronic acceptors (Chandrasekhar et al., 2017; Nastro, 2014). Electrons flow through an external circuit in consequence of a potential difference established between the electrodes, reaching a cathode directly exposed to air or soaked in an aerobic solution: there, the electrons are transferred to an acceptor (usually oxygen), while protons pass from the anodic compartment/area to the cathodic one reacting, on the cathode surface, with electrons and oxygen, delivering water as the final product of the reaction. Many different systems have been developed and tested all over the world. In general, different MFCs configurations are possible according to the geometry of the reactor, the materials used at the electrodes and for the chamber set-up, the presence/absence of a cationic exchanging membrane, the application of an external potential, the nature of cathodic reactions (Rabaey et al., 2010, Nastro et al, 2017a, Nastro et al, 2017b).

Along with wastewater treatment, MFCs can be used for various applications such as BOD and to realize biosensors for toxicity detection, bacterial enumeration, etc. Recently, sediment MFCs showed promising results for the management of constructed wetland. Electrons produced during sediment MFCs operation can be successfully stored in capacitors and subsequently utilized to drive remote sensors through a power management system (Chandrasekhar K.et al., 2017). Unlike other bioremediation processes, MFCs do not require intensive air sparging in the water or in soil/sediments: several studies proved the efficiency of MFCs in both aerobic and anaerobic/anoxic environment (Wei et al., 2015; Morris et al., 2008; Nastro et al., 2015), saving costs and energy compared to other technical solutions.

In this study, the potential application of MFC technology to the remediation of marine sediments was explored. The sediments were collected in the Gulf of Pozzuoli, a site heavily contaminated by a metallurgical plant now dismissed placed in the Bagnoli area, urban outskirts of Naples (Italy). As reported by Trifuoggi et al. 2017, these sediments are strongly polluted by heavy metals and PAHs. In this preliminary work, our attention will be focused on the removal of 16 PAHs listed by EPA as priority pollutants.

2.0 Materials and methods

The marine sediment samples were taken in different areas and depths, as shown in Table 1.

Table 1 : Sampling locations coordinates (Trifuoggi et al, 2017).

Sampling stations	Latitude (N)	Longitude (E)	Depth (m)
T4.1	40° 48.774'N	14° 9.515'E	7,7
T4.2	40° 48.546'N	14° 9.294'E	21.5
T4.5	40° 48.115'N	14° 8.819'E	98
T5.3	40° 47.412'N	14° 9.015'E	4.1
T6.1	40° 48.323'N	14° 9.768'E	5.2
T6.2	40° 48.038'N	14° 9.352'E	7.5

Samples were collected in plastic bags, wrapped in aluminum foil and sent into an ice box to the laboratory; there, they were frozen at −20 °C. The samples were inoculated in single chamber, air-cathode MFCs (double replicas). A PE Bottle (500 ml in volume) was used with 300 g marine sediment and 200 ml of sea water, in double replicas. The anode was made of carbon cloth (18 cm^2 surface) and located under 1 cm of sediment. A graphite steam 5 cm length and of 0.6 cm in diameter was placed in the water at 2 cm over the sediments surface. Sea water was conveniently aerated to provide an aerobic environment at the cathode. The system was incubated at 20 °C and kept in the dark to avoid PAHs photo-oxidation (Nastro et al, 2014). PAHs were extracted by a SPE technique and analyzed by a High Pressure Chromatography (HPLC) with UV spectrometer. Voltage was continuously monitored by an ARDUINO based MEGA 2560, composed by a load array (for polarization curves acquisition data) of six resistors ranging from 1 MΩ to 100 Ω. Power Density (PD) and Current Density (CD) were referred to the anodic surface and calculated according to the Ohm's law. MFCs design point was calculated by means of polarization curves, performed weekly. The software for data acquisition was developed with LabView Interface For Arduino (LIFA) packages.

3.0 RESULTS

3.1 PAHs removal trend

Preliminary results from T4-1, T5-3 and T6-2 revealed a significant decreasing of PAHs concentrations over the time (Figures 1, 2,3). Specifically in the case of T4-1 the percentage of removal was in the range of 40-80%, with the exception of Indenol[1,2,3-c,d]pyrene and Benzo[ghi]Perylene which showed a removal of 10 and 17%, respectively. T5-3 also showed a remarkable removal of PAHs in the range of 38-96%, with a minimum of ~30% for Indenol[1,2,3-c,d]pyrene and Benzo[ghi]Perylene. A good removal of PAHs was also determined in T6-2 (35-86%), with a minimum of ~ 25% for Fluorantene and Pyrene. In T.4-2, with the exception of Naphthalene, Acenaftilene, Acenaftene, Fluorene, Anthracene, Benzo(a)pyrene, all PAHs increased with time. This results are even more interesting if we consider that MFC-T 4.2 reversed its voltage. Further studies are needed to explain this outcome.

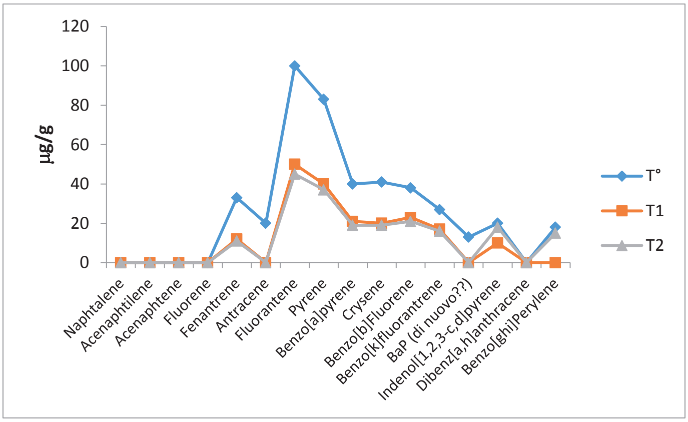

Fig. 1: PAHs concentrations in T 4-1_MFC.

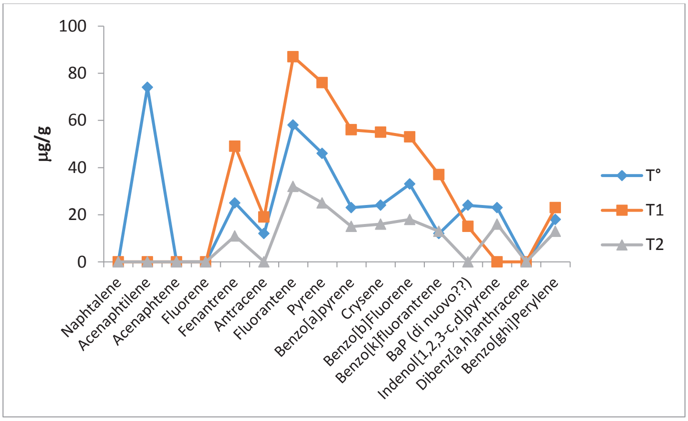

Fig.2: PAHs concentration trend T5-3_MFC sediments.

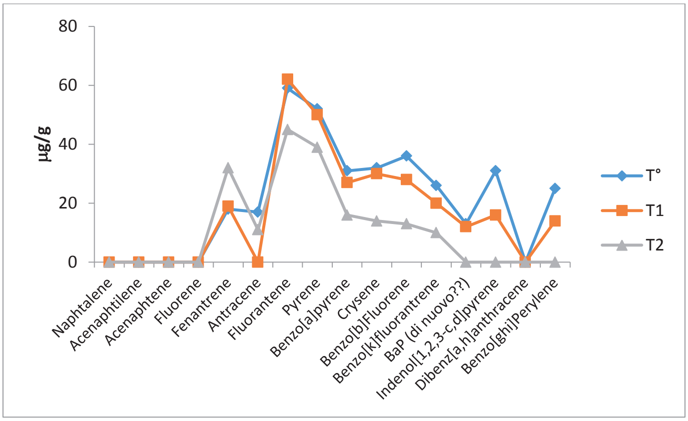

Fig.3: PAHs concentration trends in T 6-2_MFC sediments.

In T. 4-5 T.6-1 (in this last one, with just the exception of Fluoranthrene) all PAHs increased after one four weeks, decreasing after nine. These outcomes can be easily explained by the activity of bio-surfactants, naturally produced by a wide range of microbial strains (Banat I.M., 1995). Bio-surfactants can increase PAHs apparent solubility and desorption rate to the aqueous phase, acting as emulsifying agents by decreasing the surface tension and forming micelles. The produced micro-droplets encapsulated in the hydrophobic microbial cell surface are taken inside microbial cells and degraded (Nilanjana D. & Preethy C., 2011; Makkara R.S. & Rockne K.J., 2003). A such a sequence of events can be at the basis of the observed trend of PAHs concentration in our sediments.

3.2 Polarization behavior

MFCs were kept at the maximum power for all the duration of the experiment. An OCV period of about 4 hours was assured before starting the polarization experiments. Our results showed a good polarization behavior of MFCs after two weeks of operation (Figure 4), with T 5-3_MFC showing the best performance in terms of PD 20 mW/m^2 and 118 mA/m^2 of anodic surface (1200 Ω as cell design point). The only one exception was T 4-2_MFCs, which with a PD of just 4.2 mW/m^2 and a CD of 21 mA/m^2, achieved the maximum performance when connected at a 8000 Ω external resistor. After six weeks, power curves showed double peaks and hoverhooks (Figure 5), whose cause have to be further investigated, even by means of electrochemical analyses. Nevertheless, T6-2_MFC showed the highest performance with 11.7 mW/m^2 and 90.7 mA/m^2 (1200 Ω cell design point) followed by T 4-1_MFC (10.3 mW/m^2 and 39.4 mA/m^2 at 5600 Ω). Nevertheless, in order to better evaluate Sediment-MFCs efficiencies, Columbic efficiency calculations will be carried out.

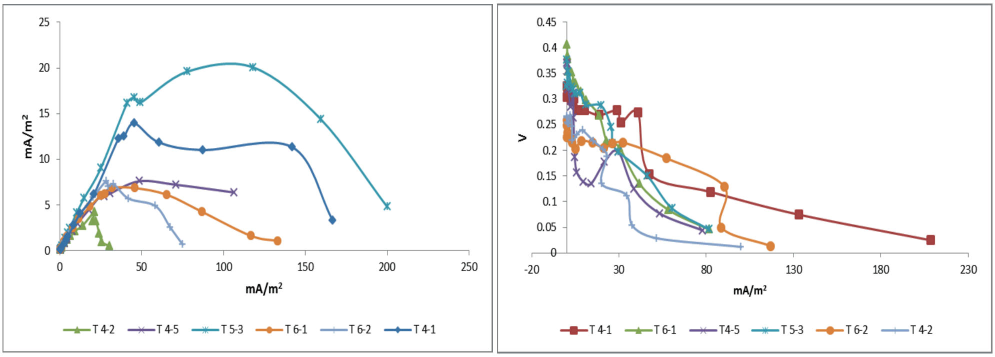

Fig. 4: Power and polarization curves after two weeks of operation.

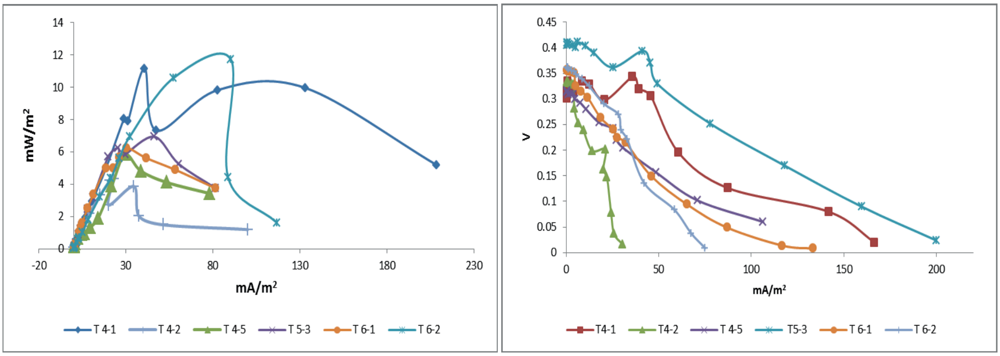

Fig. 5: Polarization an power curves after six weeks of operation at maximum power.

4.0 Conclusions

Our experiment confirmed, at a laboratory scale, the potential of MFC technology in the remediation of marine sediments polluted by PAHs. These results are more significant if we consider the high amount of other chemicals (heavy metals first of all) potentially inhibiting microbial activity and even present in our samples. A scaling up approaches based on the realization of MFCs provided with multi-anodes and multi-cathodes could improve Sediment-MFCs efficiency both in terms of PD and CD produced, with increase in PAHs removal rate. A deep study about SMFCs layout and materials, as well as SMFCs microbiology, will be of crucial importance in view of a scaling-up process and in-situ testing activity.

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Compressed air energy storage system optimization: comparison between sizing strategies depending on the time horizon of storage

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Abstract

In order to enhance the utilization of the renewable energy sources for the power generation, the development of efficient energy storage systems is indispensable.

Compressed air energy storage (CAES) is one of the most promising technologies that, recently, has received wide attention thanks to its high efficiency and to its economic feasibility. However, the main drawbacks to the affirmation of this technology are the accumulation volumes and the sizes of the fluid machines.

This paper is focused on the development of an optimization criteria for the CAES systems sizing based on choice of a time horizon of accumulation, that is the time in which it is aim to ensure to guarantee a certain availability of power in output.

The CAES system, considered in this study, is an Advanced Adiabatic CAES (AA-CAES), in which the adiabatic condition is assured by realizing a TES (thermal energy storage) unit that recovers the heat from the inter-cooling compression for satisfying the inter-heating expansion without using additional fossil fuel.

The study has been performed by comparing two sizing strategies. The first one is a "short-term" accumulation strategy, in which the storage system is designed to ensure the continuity in the power production within a full day; in this case, the storage system has several charge and discharge cycles with depth of discharge very close to 100%. The second one is a "long-term" accumulation strategy in which the storage system is able to satisfy the loads during one year; in this case, the storage system must keep great amounts of compressed air for a very long time.

Results have been presented in terms of sizes of the main CAES system components (machines, storage tanks, heat exchangers and auxiliaries), the overall efficiencies, plant lay-outs (encumbrance).

100% renewable: does this trump carrying capacity?

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Abstract

I live (with gratitude) in Burlington (pop. 42,400), state of Vermont (pop. 626,000), USA (pop. 322,000,000). We are the first U.S. city to become 100% renewable in electricity. We get hydro electricity from as far away as 700 km. (in Quebec) and as close as 1 km. Our wind energy comes from sources 20 to 250 km. distant. In our 50 MWe biomass plant we burn wood waste sustainably from 1/8 to 1/3 of Vermont's forested area. We now plan to become a "net-zero" city by 1. providing this renewable electricity (more) locally, and 2. extending coverage to present uses of fuel oil, petrol, and natural gas. (A notable exception, at least for now, is airplane fuel). I will present the areal implications of our present uses and of the net-zero plan. I see this as a return to the idea of carrying capacity, which has often been de-emphasized in waves of enthusiasm for energy efficiency, sustainability (often loosely defined), and now renewability.

-Wintergreen web site

22 April 2017, Earth Day #48

Ah, but I was so much older then, I'm younger than that now.

- Written by Bob Dylan; sung most powerfully by The Byrds.

On Earth Day #1, 22 April 1970, I shook an electric toothbrush at an elementary school class in Ithaca, New York. I drove there, but the obvious contradiction didn't complicate my thinking. That was especially ionic, because as a new physics Ph.D. I routinely did back-of-the-envelope calculations to check the feasibility of experiments and the believability of results. But then the environmental problem seemed to be about someone else's pipes spewing pollution-having little to do with me, and certainly not meriting a calculation of the relative impacts of driving and brushing teeth. I was cool: I lived in a cabin with a woodstove and an outhouse and drove a Volkswagen.

47 years later, I do environmental calculations, mostly about energy, all the time-in fact, for a living. I know about indirect pathways, growth, ecological footprint, the power (and frustrations) of I=PAT. I know about the pressures for economic growth (from the top and the bottom) and the energy cost of living, about lags in all systems, about denial, about the perennial hope and trust in new technical innovations, and citizen and specialist burnout. I know toothbrushes are a drop in the bucket.

From Earth Day #1: Carrying capacity

We learned what carrying capacity means (with plenty of arguments and caveats) from the fallout of the 1960s and Earth Day. Carrying capacity is based on a blend of intensity of impact and area, an application of the simple, hackneyed, and pivotally important equation I=PAT. In 1972 "The Limits to Growth" was published. Its major message was about the positive feedback/exponential growth/dynamics and lags, but always in a context of limits. Its models were for the entire world, so it was concerned with global limits.

1973 forward: Enter efficiency

Following the Mideast oil embargo in 1973, U.S. consciousness was blitzed by realizations and resolutions about energy-use efficiency. We learned and internalized that the desired product was energy service (say refrigerated space, travel from A to B, or dancing electrons) and that with consciously designed technology, we could get much more energy service from a unit of energy. We are now familiar with the success trajectory: in 2016 we Americans used about the same total energy as in 2000 but produced 26% more GDP. Locally, Burlington, VT's electricity use is essentially the same as in 2000 thanks to Burlington's activist efficiency programs in a time of dramatic economic growth.

Over my career, I did some work on introducing efficiency into energy planning. Among my near and far colleagues were the innovative, persuasive analysts and proponents of efficiency. These pioneers established academic programs at universities (e.g., Berkeley, Princeton, Michigan, Copenhagen) and elsewhere, and spearheaded the establishment of e.g., the American Council for an Energy Efficient Economy. Even then, however, I felt uneasy: improved efficiency was often emphasized as the goal itself, not the means to hold environmental impact to boundaries based on total ecological/social/economic system capacity...local, regional, national, and global. No-growth at today's consumption level does not guarantee that. Certainly, many voices drew attention to this, but the buzz from the field was to tacitly equate more efficiency with success.

<u>1980s forward: Hey, it's sustainable</u>

The Brundtland Report (1982) coined sustainability and defined it thus:

> *"...development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

- Our Common Future World Commission on Environment and Development

This is imprecise if not outright vague. Scientists argued about what it means in biophysical terms, while business interests, politicians, and the other usual suspects cast it in their own favorite tropes. So "sustainable development" quickly morphed into "sustainable growth", sustainable meals, sustainable construction projects, and so on. Of the many uses of "sustainable" out there, almost none incorporate the hard thinking and breadth of concern that started it all. As with efficiency, the means tended to become the end. The consequence was that the energy analysis world and the larger society tended to equate efficiency with sustainability.

<u>2000 forward, particularly in Vermont, especially in Burlington: Does renewability say it all?</u>

The dramatic cost dive of solar and wind energy in the 21st century is inspirational, and makes a transition away from fossil fuels almost inevitable instead of its dream-play status in the 20th. Certainly, there are difficult issues about timing, inertia, and equity, along with resistant people, corporations, and governments. (Ironically, the U.S. has a disproportionately large cadre of the latter.) But it's a wave that has arrived. For example, in Burlington the local utility is 100% renewable (a mix of hydro, wind, biomass, and solar). Of course, even that renewability can be argued: are forestry-based wood chips, which feed our McNeil Power Plant, truly renewable over many harvests? Does Hydro Quebec's replumbing of ca. half the province's watershed area qualify? Does selling and buying renewable energy credits to keep our per-kWh rate low jibe with a fair definition? And so on. My concern here is that renewability is the newly touted substitute for, or equivalent of, sustain ability.

Being renewable and local returns us to the size question

To put it baldly, do we now say uncritically that if it's renewable, more is better? Will there be a land-use crunch? After all, critics of solar electricity rightly point out that sunlight is diffuse relative to coal, oil, or natural gas, or even nuclear-and they have a point. (That point is itself challengeable based on indirect impacts.) This areal impact ("footprint") question figures in a new vision of Burlington Electric Department (BED), encapsulated in the recent strategic plan:

BURLINGTON ELECTRIC DEPARTMENT
2016-2017 STRATEGIC PLAN

MISSION

To serve the energy needs of our customers in a safe, reliable, affordable, and socially responsible manner.

VALUES

Safety
Integrity
Community
Engagement
Innovation

10-YEAR VISION

Transition Burlington to a "net zero energy city" across electric, thermal, and transportation sectors by reducing demand, realizing efficiency gains, and expanding local renewable generation, while increasing system resilience.

Let us set aside for now the bold and exciting extension of BED's purview to fossil fuels and not just electricity. And let's acknowledge that BED is already 100%* renewable, the "*" indicating several persistent arguable components mentioned above. Instead, let's concentrate on areal impact, i.e., actual footprint. As we become more local we will pull the distant footprints closer and make them more visible. These land demands will compete with many other uses. How that area compares with Vermont's area will occasion and require a return to confronting carrying capacity, full circle from Earth Day #1, 47 years ago.

Vermont's electricity's footprint today

Rough calculations give these size indicators for electricity (all assuming that we develop lossless storage for electric energy to solve the intermittency problem):

Solar:

1. All of Vermont's current electricity can be sourced from PV solar on ca. 0.5% of the State's total area of 25,030 square km.
2. For Burlington, the analogous portion is ca. 17% of the City's 27.3 square km.

Wind:

1. All of Vermont's current electricity can be sourced from wind turbines on ca. 298 km. of high ridgeline sites. (The Long Trail, which follows the crest of the Green Mountains across the state, is 440 km long.)
2. For Burlington, the analogous portion is ca. 18 km. of ridgeline.

Biomass:

Burlington shares the McNeil (biomass) Power Plant 50:50 with Green Mountain Power. Our share provides 40% of our electric energy and requires wood chips from ca. 4% of Vermont's area in "sustainable forestry". (For the entire plant this is 8%.) These are very rough numbers; more accurate research indicates that Vermont's forest could support only ca. three McNeils.

Hydroelectric energy:

1. 31% of the State's electric energy is hydro, dominated by large dams on the Connecticut River. It is estimated-roughly-that further instate development could raise this by 35%-50%, the latter figure being very optimistic.
2. 29% of Burlington's electric energy is from hydro, as follows; 18.7% from New York State, Maine, and Quebec; 9.7% from Vermont; 7.6% from within Burlington (Winooski River). There is no additional in-city potential.

Upshot. How big should we be?

At the moment, we get electricity generated from as far away as 700 km (hydro), 250 km (wind). 100 km (biomass, mostly from Vermont), and within city limits (solar, hydro). How local can be in sourcing all our energy? Some of the numbers above show lots of opportunity. Some show that we are pushing limits. Should these limit-realities mean anything, have anything to do with our expectations, desires, plans, policies, and dreams?

E. O. Wilson proposes that half of the earth should be set aside for nature. The reasons span spiritual/religious, scientific, economic, and social issues. In the empty world into which modern humans radiated ca 100 thousand years ago, the question of when “enough becomes plenty” (or perhaps better, when “plenty is enough”) was moot; we had no discernable effect. We know that is no longer true. Even in “green” Vermont the per capita land is about 3.8 ha.; some other states and countries are compared in Table 1.

	Persons/km^2
Montana	2.7
Australia	2.8
Canada	3.7
Quebec	5.9
Maine	16
Brazil	22
Vermont	26
US (50 states/48 states)	34/40
California	99
China	145
New York State	165
Nigeria	165
Italy	206
Japan	353
New Jersey	494
Bangladesh	1230
Burlington, Vermont	1550

Table 1. Population density for selected political units.

Apology: In my...mature... years I am returning to the implicit idea of limiting overall growth, and paying less attention to the analytical details. One asks: is this wisdom based on experience, or just because it is getting more difficult to do the mathematics? I will comment on this question.

Optimization criteria to evaluate the switching process from an individual heating to a district heating strategy for the city of Pompeii

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Abstract

In this paper, the authors present an optimization analysis aimed to evaluate the switching process from an individual heating to a district heating strategy for the city of Pompeii. The new energy system proposed utilizes PV panels, solar thermal panels and cogeneration plants to produce electric and thermal energy to supply the district heating, in order to meet the thermal residential energy demand of the city. The new energy system is analyzed with EnergyPLAN and TRNSYS software. The authors propose a reference scenario dating to 2010 and a future scenario by 2030 to validate the model proposed. The whole system behavior is analysed considering different time bases: daily, weekly and yearly. The EnergyPLAN outputs include the aggregated yearly production and demands of the modelled energy conversion systems considered, as well as hourly values useful to identify the measures to make Pompeii a nearly zero carbon city in the residential sector. The analysis shows that it is possible to meet the demand of the residential sector of the city using the local resources available on the territory.

1. Introduction

Over the last twenty years, energy efficiency and energy consumption reduction have been two of the key issues of the political debate. The excessive consumption of fossil fuels involves both environmental and political problems. Europe has a low percentage of energy reserves of natural gas and oil and is therefore characterized by a strong dependence on energy from abroad. In order to overcome this problem, the European Union is implementing policies aimed at reducing consumption and exploiting renewable resources [1-2]. The European Commission launched the Covenant of Mayors [3] to endorse and support the efforts deployed by local authorities in the implementation of sustainable energy policies. The Covenant of Mayors, now called Mayors for Climate and Energy, contributed to the wider policy objectives of the Europe 2020 strategy. Thus, many municipalities are developing energy plans to harness the locally available energy resources in order to turn themselves into cities running on renewable energy. Even the city of Pompeii has developed its own plan aiming to reduce by 20% the CO_2 emissions. As underlined in the Sustainable Energy Action Plan, the process to become a fossil fuel independent city is not a sudden transition, as a series of specific actions need to be taken and evaluated from an environmental, economic and technical point of view. This transformation will take some years, thus planning a strategy for the whole energy system for a country, region or city [4] is very important and is strongly encouraged by the European Union [5]. In this sense, district heating is going to play a key role in the future fossil-free energy system, because it can provide energy savings and flexibility to fluctuating electricity generation, matching the electricity and heating sector [6]. It should also be considered that in 2010 approximately 70% [7] of the population of the world lived in urban areas, with a high density of buildings; this condition a very strong argument for using DHC [8] in the future development of the energy system of cities [9]. Therefore, in this paper the authors have focused on the measures to be implemented for the residential sector to replace existing technologies used for heating and cooling with a district heating and cooling net. The analyses are carried out with Energy Plan and TRNSYS software [10-11].

1.2 Geography and population and residential features

Pompeii is an Italian town of the Campania region in the province of Naples. City area is 12.41 km^2, population of 25397 inhabitants (ISTAT survey Dec. 31, 2014) and population density of about 2046.5 / km^2 [14]. Elevation is 14 m above sea level in the Sarno plain, between the southeastern base of Mount Vesuvius and the Lattari Mountains towards the sea. Figure 1 shows the location of Pompeii in the Campania region and the trend of the population in the Municipality from 2001 to 2016. In the period under investigation, the number of residents remained mostly constant with a slight decrease of about 0.84%. In 2003, the maximum value was 25820 inhabitants, while in 2011 the minimum was 25465.

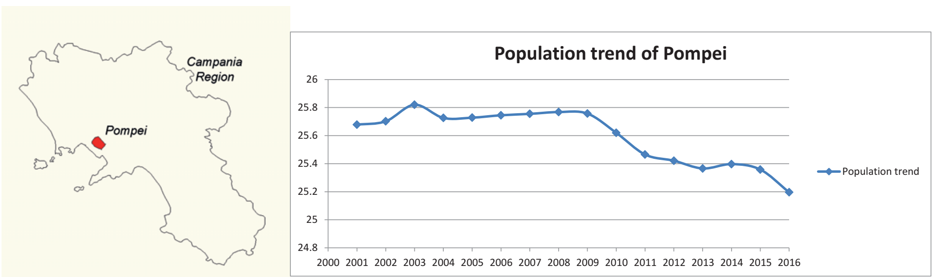

Figure 1

Based on the information provided by the Municipal Urban Plan proposal [12], the citizens of Pompeii reside mostly near the historic center and the south of the city.

1.2 Reference scenario

The reference scenario was outlined using the data of Pompeii Sustainable Energy action Plan. This scenario is used as a benchmark for the new strategy for the residential sector proposed in this paper by the authors. The reference model was implemented in EnergyPLAN environment. In particular, the yearly and hourly electricity demand was obtained from Terna S.p.A data [13]. The transient behavior of an energy system must be evaluated using a dynamic model such as the EnergyPLAN model. Among the tools reported in the literature, the authors have chosen EnergyPLAN because it had been previously used to simulate a renewable energy system for several cities such as Aalborg and Frederikshavn [15-16].
EnergyPLAN can be used to design and analyse the energy system/infrastructure on an hourly basis with reference to a typical year, including electricity, heating and cooling, energy consumptions of residential, industry and transport sectors.

- An energy plan for a territory, obtained from a comparative analysis of several alternative energy systems;
- A clear methodology to yield results understandable to all stakeholders.

Table 1 reports the reference database used in order to set the reference scenario in EnergyPLAN software.

Table 1 Reference Databases used for the reference Scenario

Sector	***Gasoline***	***Diesel***	***LPG***	***Heating oil***	***Electricity***	***Biomass***	***Waste***	***Natural Gas***
Residential	ISPRA	ISPRA	ISPRA	ISPRA	TERNA	ISPRA	ISPRA	ISPRA

As reported in Table 2 the Residential sector is characterized by a high consumption of Electricity and Natural Gas. The sector is the largest consumer of primary energy (34%).

Table 2 Primary Energy Consumptions for Residential Buildings (MWh)

Sector	***Gasoline***	***Diesel***	***LPG***	***Heating oil***	***Electricity***	***Waste***	***Biomass***	***Natural gas***	***Total***
Residential	*0*	*592*	*13612*	*0*	*27496*	*0*	*11919*	*25747*	*79367*

3. The new proposed energy system for the city of Pompeii

Energy planning has to take in account the local energy demand and the renewable resources in order to convert Pompeii into a low carbon emission city. Moreover, the plan should establish provisions concerning incentives to use local available renewable energy resources. In this way, the energy import is reduced and environmental and economic benefits are assured.

The use of renewable energy sources must be "sustainable", this means that there should be no waste. For this reason, the renewable exploited sources have to fuel a smart energetic system of the city. A smart energy system is capable of managing energy without wasting it.

As of today, the thermal and cooling energy system of the residential sector of Pompeii is based on individual plants; in most buildings, a natural gas boiler is installed in order to supply the thermal demand. Electric splits or heat pumps generally guarantee the cooling performance. Furthermore, the use of renewable energy in the thermal system has to be managed separately for each individual building. In fact, solar thermal panels are installed in the buildings to meet the related heat demand.

The national grid provides the energy used in the electric system. PV systems have been installed in the buildings but they supply only 3.6% of the total need.

Pompeii needs a new energy system in order to become a low carbon city. The new system shall be able to use the available energy resources and manage them through storages and "smart" distribution. The storage serves to manage the fluctuation of the energy production (e.g. energy from wind and sun); energy is best moved from production the demand through a smart distribution system.

In this paper, the authors focused on the definition of the new smart energy system in order to use the renewable energy resources available locally and to supply the energy demand of the city of Pompeii.

The two systems currently in use, electric and thermal/cooling systems, must be converted into a single smart system. The two systems are interconnected and the energy production of both electricity and heat rely on one single strategy.

PV and solar thermal plants feed the electric grid and a district heating/cooling, respectively. The choice to use only PV and solar thermal plants is due to the large availability of solar energy. The low wind velocity and the densely built areas rule out the possibility of installing wind turbines as well as geothermal plants.

The proposed district/cooling system is a fourth Generation District Heating (4GDH) characterized by low-temperature water in the grid [9-15]. This allows to reduce the heat losses of the grids and to use low–temperature energy resources (e.g. geothermal energy, solar energy, etc.). Conversely, the change in temperature demand of buildings may be assured by introducing heating systems that can use supply temperatures of 40-50°C (e.g. floor heating or wall heating with an average water temperature just a few degrees higher than room temperature). The building cooling demand is met by installing the adsorption plants in the substation.

The "key" plant of the proposed energy system is the CHP system. In fact, the CHP with both types of energy production acts as a connection point between the electric and thermal grids.

4. Methodology to design the new energy system

The outline of the new energy system focuses on the CHP plant design. This paper approaches the CHP plant design in accordance with the fluctuations in PV plants. The CHP power is determined in order to meet the electricity demand when the PV production is not sufficient (in the night or during overcast winter days). The heat production by CHP plant must serve the district heating. This strategy avoids the issue related to surplus of electricity produced, while there might be a risk of heat surplus. Large thermal storage systems can be installed in order to store, at least in part, the surplus energy.

The surplus electricity production (SEP) by PV plants is used to feed heat pumps or, when the heat demand is already met, it is delivered to the national grids (ESEP). The national grids are based on existing high-power transmission lines delivering high power capacity. When the electricity production is higher than the line capacity, the critical surplus electricity production (CSEP) problem has to be solved [19] . In the [4], the CSEP problem is solved by delivering the electric energy to neighboring municipalities. According to the *Europe 2050* program, each municipality shall be able to reduce the CO_2 emissions becoming a low carbon city [9]. For this reason, the ESEP production has to be minimal because the neighboring municipalities may not need electric energy, having already satisfied the demand using their own plants. In this work, the authors have designed CHP plants by minimizing the ESEP problem.

The software used by the authors to define the new energy system is:

1) TRNSYS software [11] to simulate the PV and solar thermal plants. The mathematical model implemented in TRNSYS for PV systems is the De Soto while for water heating purposes, the model used is that of the medium-temperature collectors with flat plates.

2) EnergyPlan software [10] to simulate the whole energy system. The TRNSYS outputs were used as input data in EnergyPlan.

5. Results

The new energy system is designed based on the following assumptions:

1) The yearly and hourly trend electric of energy consumption in residential buildings for lighting and utilities (26.0 GWh_e/year not including the cooling) is equal to the current ones;

2) The yearly thermal demand is calculated from the data concerning the residential fuel consumption reported in Pompeii Sustainable Energy Action Plan and considering the bellows efficiency: 0.850 and 0.900 for oil/GPL and natural gas boilers, respectively. The total thermal demand is equal to 50.0 GWh_t/year.

3) The yearly thermal energy production by biomass plants in residential buildings is equal to that of SEAP and it has not been taken in account in the district heating demand;

4) The yearly cooling demand was estimated using the methodology reported in [17]. The yearly value obtained is equal to 5480 MWh_e/year. The cooling demand is met by installing the adsorption plant, which is characterized by an efficiency equal to 0.400. Consequently, the heat demand of district heating in order to assure the adsorption operations is equal to 13700 MWh/year. This value has to be added to the heating demand to the of 50.0 GWh_t/year. Meeting the cooling demand by using the district heating also implies a reduction in electric energy consumption. In fact, in the new energy system, the absorption machine has replaced splits and heat pumps.

The current electric energy consumption, equal to 28.0 GWh_e/year, was reduced by an amount equal to 1827 MWh_e/year. The latter is obtained considering a SCOP or EER of splits and heat pumps equal to 3.00;

5) The hourly trend of the thermal and cooling demand was calculated as a function of the outdoor temperature and air-sun temperature, respectively. A complete description of the procedure is given in [4].

6) The heat losses of grids were considered equal to 20% of the heating demand [18] increasing the value of the heat district demand to 60.0 GWh_t/year.

The design was outlined gradually. At first, a sensitivity analysis was carried out in order to find the PV power able to balance the import and export of electrical energy. Figure 2, reports the electrical energy produced by PV plant by varying the PV power installed. The fluctuation of PV production implies an energy surplus during the daily hours and the take-up of electricity at night. When the PV power is equal to 22.0 MW_e, the balance between imported and exported energy is achieved. In this case, the national grid was used as an electric storage system. The ESEP value is very high (18.0 GWh_e) implying a high risk of generating a CSEP problem. In order to reduce the ESEP value, a CHP plant was designed to meet the electric demand when the PV production is not sufficient and to balance export and import electrical energy. Obviously, the CHP size varies depending on the value of PV power installed (*Figure 3*). In particular, the largest CHP size has to be installed (6.77 MW_e) when the PV plants have not been taken into account. The lowest value of ESEP is achieved when the power of PV plant is equal to 7.00 MW_e and the CHP size is equal to 3.86 MW_e (Figure 4). This scenario appears to be significantly less risky than the other, due to the lower value of ESEP (8.46 GWh_e). For this reason, the authors decided to continue to analyze only the latter scenario. It was possible to further reduce ESEP by using the surplus electricity for heat pumps. The heat production is fed into the district heating. Figure 5 shows the exportable electric energy depending on the heat pump power installed. Power heat pumps for over 8.00 MW_e do not imply further electrical energy reduction and the value of 3.11 GWh_e/year for ESEP is achieved. Finally, a heat-storage capacity was taken into account in order to increase the operation period of HP. The storage system accumulates the thermal energy produced both by HP and CHP. The increase in capacity of the storage over the 40MWh does not imply any reduction in the exported electricity because at certain times of the year the heat demand is very low (mid-seasons) and the storage saturation may occur. Despite the efforts of the authors, the ESEP value is above zero. The surplus electricity problem can only be solved through the exchange of energy flows with the neighboring municipalities or with the integration of electricity storage systems.

As regards thermal energy, the CHP and HP production is not sufficient to meet the residential demand. In fact, despite the storage capacity of 40 MWh_t, 19.0 GWh_t are requested to supply to the district heating. A solar thermal plant can be integrated in the smart energy system. The solar thermal production can be able to meet the demand. As shown in Figure 7, the unusable solar thermal energy accounts for a significant proportion of the production energy. In the case of 60 GWh_t of energy produced by the solar system, the values of both used and wasted thermal energy are comparable, which does not justify the installation of a large solar thermal plant. A further storage device does not affect significantly the district heating demand. In conclusion, the installation of a peak-load biomass boiler is the only best option.

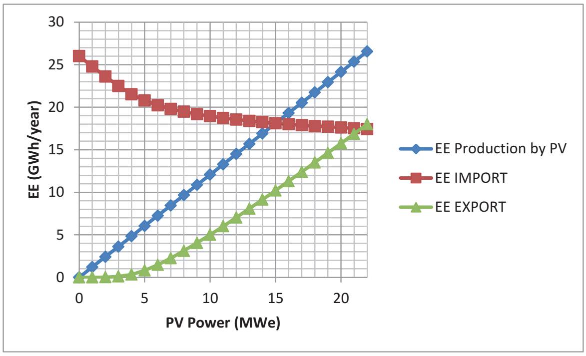

Figure 2 Electrical energy production by PV plants, Electrical Energy imported by the national grid and Electrical Energy exported to the national grid.

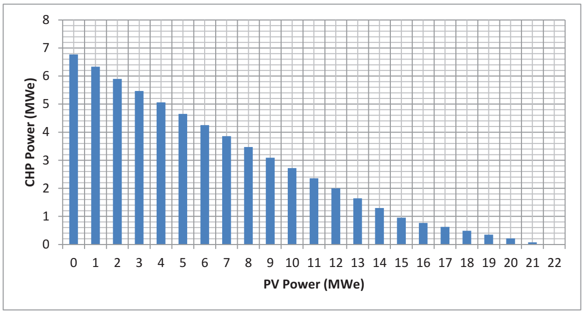

Figure 3 CHP power needs to balance the export and import electrical energy depending on the PV power installed

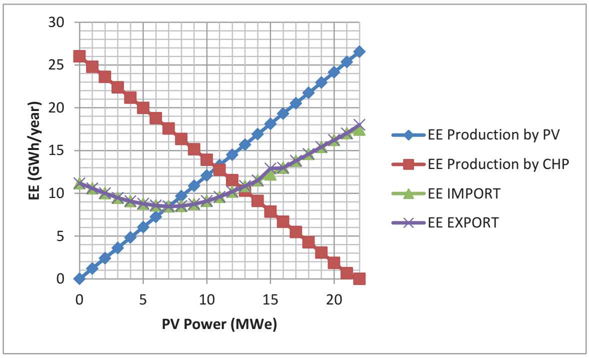

Figure 4 Electrical energy production by PV plants and by CHP plants, Electrical Energy imported by the national grid and Electrical Energy exported to the national grid.

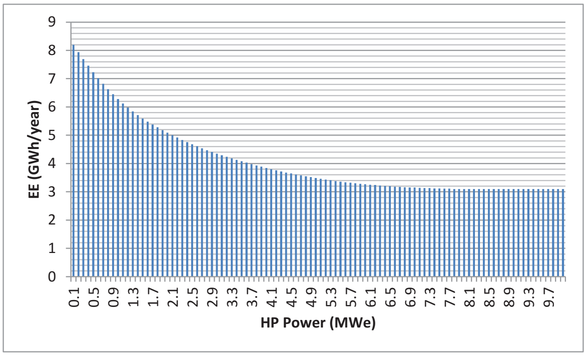

Figure 5 Electrical energy exported to the national grid as a function of HP power installed

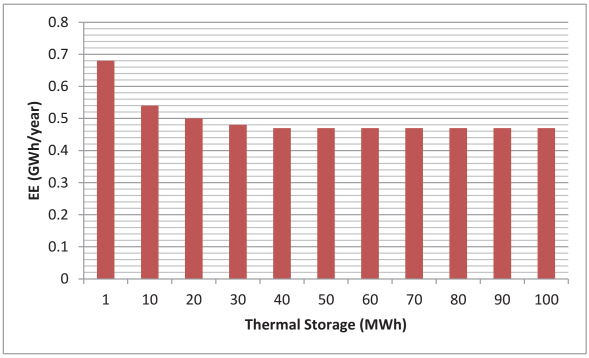

Figure 6 Electrical energy exported to the national grid as a function of the thermal storage capacity

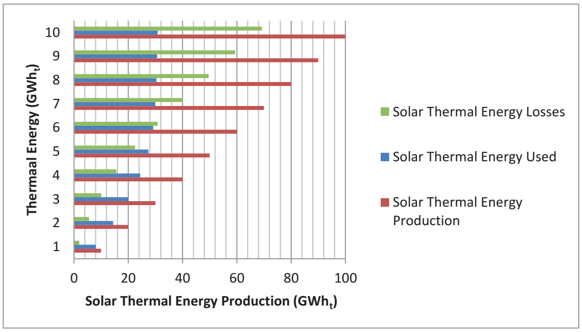

Figure 7 Solar Thermal Energy Production, Used and Lost

5. Conclusions

The authors present a new methodology to design a smart energy system able to provide energy for residential purposes in order to meet the energy demand by using renewable sources. The smart energy system proposed consists of PV and solar thermal plants in order to fuel the smart electric grid and the district heating/cooling systems, respectively. CHP plants are designed to meet the electricity demand when PV production is not sufficient. Although the CHP operation is designed based on the fluctuations of PV, the value of exported electrical energy remains high. For this reason, heat pumps are integrated to use the surplus of electricity produced and feed the district heating. A solar thermal plant and a large storage device are integrated to meet the remaining heating demand but a biomass boiler needs to be installed to cover the peak-load. The outlined scenario is characterized by a low electric energy export which still remains greater than 0. The surplus electricity can be delivered to neighboring municipalities to avoid the issue related to the surplus of electricity produced.

6. Future work

A second methodology will be investigated in a future work. In fact, the CHP plant could be designed in according to the fluctuations of solar thermal plants. Moreover, an economic analysis will be taken into account to compare the two methodology proposed.

Nomenclature

CHP	Combined Heat and Power
CSEP	Critical Surplus Electricity Production
DHC	District Heat and Cooling
EER	Energy Efficiency Ratio
ESEP	Excess Surplus Electricity Production
4GDH	4^{TH} Generation District Heating
HP	Heat Pumps
PV	Photo Voltaic
SCOP	Seasonal Coefficient of Performance
SEP	Surplus Electricity Production

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Wastewater sludge dryer coupled with an ORC system powered by geothermal energy

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Abstract

Waste treatment and disposal is a crucial challenge in small islands, due to scarce availability of land and environmental restrictions. For this reason, the most common strategy is to ship waste to the mainland, despite the high economic, energetic and environmental costs. Another critical issue in small islands is energy supply, due to the lack of connections with continental energy networks. Transportation of fossil fuels for local energy production increases both the energy cost and the greenhouse gas emissions. As a consequence, the use of renewable energy sources is very attracting in small islands. Waste disposal and energy production are often strictly related since waste treatment is energy-intensive, making the use of renewable energy sources useful to face both challenges. For this reason, a thermal dryer for sewage sludge treatment coupled with an Organic Rankine Cycle (ORC) system powered by geothermal energy, is proposed in this work. The analysis is carried out for the case study of Pantelleria, a small island in Southern Italy. Currently, sewage sludge on the island is dewatered to a final water content equal to 70-80%, whereas the proposed dryer can reduce such parameter to 10%. This would significantly decrease the economic, energetic and environmental costs for transportation and final disposal. The geothermal source is used to produce both electricity to supply the internal demand for the wastewater treatment plant, and thermal energy for the sludge dryer. Electric energy is produced by a small scale ORC system and the desiccant current is heated through the geofluid in an air-water heat exchanger. The profitability of the proposed system is measured by several economic indicators and compared to that of a conventional layout, where the desiccant current for sludge drying is produced through a boiler powered by fossil fuel and the electricity for wastewater and sludge treatment is supplied by the local grid.

1. Introduction

The majority of small islands face some common problems, such as energy dependence, waste management, and fresh water availability (Chen et al. 2007). These problems usually increase during high season, due to touristic activity, which characterize small islands (Maria, and Tsoutsos 2004). Tourism inflow represents a significant income, but at the same time it reduces land availability for waste disposal, and increases energy and water demand as well as waste production (Alves et al. 2000).
Waste disposal is one of the major issues affecting small islands. The scarce land availability and the environmental restrictions limit the options for waste management (Chen et al. 2005). In general, its cost, related to waste generation, is higher than in continental regions, due to the diseconomies of scale and deficiencies of the system (Hernández, and Martín-Cejas 2005). In addition, tourism activity, not only increases waste generation (Shamshiry et al. 2011), but it also makes unfeasible landfilling and other waste treatments, such as incineration or composting. For this reason, the most common strategy is to ship waste to the mainland (Chen et al. 2005), despite the high economic, energetic and environmental costs. Shipping waste to the continent is

often used also for sewage sludge, that is the solid by-product of wastewater treatment. In general, sludge production is increasing due to more restrictive standards concerning the quality of water effluents introduced in last years (Kelessidis, and Stasinakis 2012). In small islands, it has to be considered that population and, as a consequence, wastewater and sludge production increase during peak periods of tourism. Wastewater and sewage sludge treatment is high energy-consuming (Di Fraia et al. 2016), representing a critical issue in small islands, where energy generation is based on importation of fossil fuels. Usually diesel generators are employed for power generation, with high costs and polluting emissions, and the dependence on price-volatile diesel fuels (Blechinger et al. 2014), that can be 3–4 times higher than that in the mainland, making vulnerable the island economy (Kuang et al. 2016). In addition, sometimes the connection with continental energy networks is scarce, making difficult to obtain a continuous and reliable supply (Alves et al. 2000).

For these reasons, the use of other Renewable Energy Sources (RES) should be promoted to reduce energy importation, with related costs and CO_2 emissions, and to enhance security of supply, self-sufficiency and sustainability. Although it has been demonstrated that small islands can profit from the use of RES (Blechinger et al. 2014), their use has been estimated to be less than 10% of the total energy production (Kuang et al. 2016). RES are potentially available in almost all small islands, but they are not commonly used (Mitra 2006) or properly developed (Alves et al. 2000). This is also due to the intermittency and randomness of some RES and to the problems related to grid integration as well (Chen et al. 2007).

Several methodologies are proposed in literature to assess the integration of energy and resources use. One approach, called RenewIslands (Duić, and da Graça Carvalho 2004), is based on the mapping of island's needs and resources, the identification of several scenarios considering different technologies to exploit the available resources and to cover the needs, and modeling of these scenarios (Duić et al. 2008). Another methodology, based on different RES technologies/configurations, has been implemented in the European project EMERGENCE 2010. Firstly RES potential is identified through GIS-based data, used to classify and list the resources; taking into account financial, environmental, technical and social parameters the most viable solutions are recognized and analyzed through pre-feasibility and feasibility studies (Oikonomou et al. 2009).

Geothermal energy, an effective RES which is not intermittent, refers to the heat from the depths of the earth, which usually exists in volcanic areas. There are two forms of geothermal energy utilization: geothermal direct heating and geothermal indirect energy generation. Over the years, geothermal generation has undergone a rapid development in the world. The average annual growth rate in cumulative capacity was 3% from 2010 to 2012 and reached 4% in 2013 (REN21 2014). The total installed capacity and electricity generation reached 12,000 MW and 76,000 GW h respectively in 2013, with an estimate increase to 19,800 MW in 2015 (Kuang et al. 2016).

Many islands are in the plate junction or derive from volcanic activity, so they have a great potential of geothermal energy (Bertani 2012). As an example, from geothermal energy 27.8 MW were generated in 2008 in São Miguel (Camus, and Farias 2012), 102 GWh of electricity in 2005 in Guadeloupe, 10 TWh of in 2010 (equal to 17% of the nation's electricity production) in the Philippines, which is the world's second largest producer of geothermal energy for power generation (Bertani 2012). However, except for few examples, due to the high investment cost and geographical restrictions, the use of geothermal energy is still limited (Kuang et al. 2016).

In this work a sewage sludge dryer coupled with an Organic Rankine Cycle (ORC) powered by geothermal energy is considered, since ORC is one of the most suitable Thermally Activated Technologies (TAT) for power generation from low-medium enthalpy heat sources.
Thermal drying is very energy-intensive, so the use of RES has been suggested to reduce the environmental impact of the process (Bux et al. 2002) and geothermal energy has been recognized to be successful for drying and dehydration at moderate-temperature (Lund 2010). It is commonly used in agriculture, for drying vegetable and fruit (Lund et al. 2011). In industrial applications, geothermal energy is used for drying of diatomaceous earth (Ragnarsson 2005), pulp, paper and wood (Bloomer 1997), whereas no systems for sewage sludge drying have been developed. In authors' knowledge, a similar system is here investigated for the first time. Beckers et al. carried out a technical and economic analysis of a hybrid geothermal-biomass cogeneration system, where geothermal energy is used to power an ORC and a district heating system before to dry biomass for gasification (Beckers et al. 2015). Ambriz-Diaz simulated a system based on a geothermal cascade, composed of three thermal levels, at decreasing temperatures: an ORC for electricity production, an absorption refrigeration cycle for ice production, and a dehydrator for drying of agricultural products (Ambriz-Díaz et al. 2017). Islam and Dincer proposed an energy and exergy analysis of a solar and geothermal energy-based system, composed of two ORC power turbines, two thermal energy storage systems, an absorption chiller, a heat pump for space heating and a dryer (Islam, and Dincer 2017). Ezzat and Dincer simulated a multigeneration system, consisting of a single flash geothermal cycle, a heat pump system, a single-effect absorption cooling system, a thermal energy storage connected with auxiliary steam turbine, a hot water system and a food dryer (Ezzat, and Dincer 2016). Ivanova and Andonov developed a system for crop drying, where desiccant current is produced using solar energy and geothermal water (Ivanova, and Andonov 2001, Ivanova et al. 2003).
The layout of the novel system developed in this work is described in Section 2, and the simulation model used to assess its performance in Section 3. Through the proposed model the case study of Pantelleria, a small island of Southern Italy, is analyzed and the main results are reported in Section 4. Finally, some conclusions are drawn in Section 5.

2. System layout

A novel wastewater sludge dryer coupled with an ORC powered by geothermal energy for the island of Pantelleria is proposed. According to the available literature (Gianelli, and Grassi 2001, Granieri et al. 2014, Fulignati et al. 1997, Della Vedova et al. 2010), geothermal inspections in Pantelleria revealed hydrothermal basins with 140°C at 300 m in depth and 240°C-260°C at 600-800 m in depth. Therefore, Pantelleria is included in the highest rank of geothermal potential according to the Italian classification (Trumpy 2014).
Currently, no wastewater treatment is performed in Pantelleria island. An executive project is in progress, to install a compact unit which performs solids separation, sludge thickening and mechanical dewatering. The real data of such project are considered in order to design the system proposed in this work.
The geo-fluid is pumped and employed to heat fresh air for sludge drying. A fraction of the desiccant stream exiting the dryer is recirculated to reduce at the same time flow rate of the exhausts to be treated and energy demand of the process. The recirculated desiccant current is mixed with the heated air in order to increase its temperature. In the second step, before being rejected, the geo-fluid is used to power

a small-scale ORC system, operating with R245fa, which is a suitable working fluid for temperature heat source up to 170 °C (Calise et al. 2014). The ORC condensation process is performed by using purified water coming from the wastewater treatment, in order to save fresh water. The ORC is designed to supply the electric energy demand of the wastewater treatment system, the dryer and the pump for the geo-fluid. The system is sketched in Figure 2.1.

3. Simulation model

The system is modelled through the software ASPEN Plus (Advanced System for Process Engineering). Geothermal source is fixed at 160°C with 1.00 kg/s of mass flow rate. Sludge is dried, with a two-stages process to enhance water removal, in order to reach at least 90% of solids. Thermodynamic properties of air are determined through Raoult's and Henry's laws, implemented in ASPEN Plus (2010).

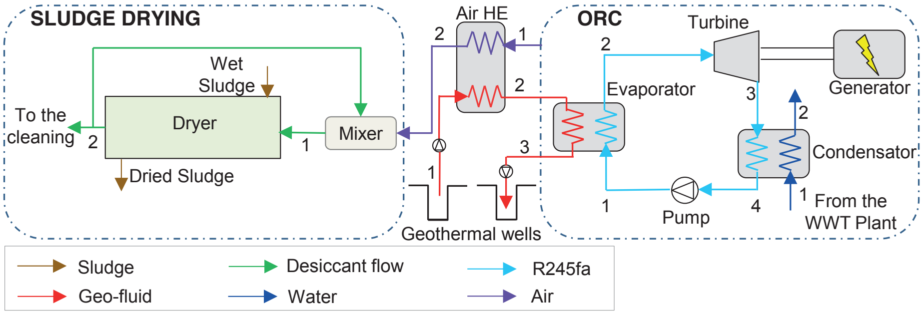

Figure 2.1: System layout.

Sewage sludge is modelled as a carbonaceous fuel (Brambilla 2014) by using two main algorithms implemented in ASPEN Plus, that calculate specific heat, density and enthalpy of coal and coal-derived substances, through statistical correlations based on the biomass ultimate, proximate, and sulphur analyses (Raibhole, and Sapali 2012). In the convective dryer, the Peng Robinson-Boston Mathias modified method is used since the system deals with multiple phases (Brambilla 2014). The convective dryer is considered to operate in cross-flow mode for the gas and plug flow for the solids. The kinetic of the process is implemented through the drying curve, that expresses the evaporation rate depending on the water content.
The ORC module, using R245fa as working fluid, is calibrated in order to constantly supply 25 kW of net power output. The heat exchangers adopted are Shell&Tube, whose geometrical and thermodynamic features are determined by means of Aspen Exchanger Design&Rating software.
The expander is supposed to be a micro-turbine fed by saturated vapor, while the pump is fed by saturated liquid. Both the turbine and the pump work at fixed isentropic efficiency. Pressure levels are set supposing 5.0°C of pinch point temperature. Inlet temperature of condensation process is fixed at 20°C, while the maximum temperature is fixed at 26°C (as recommended by the Italian legislation for water discharge into the sea (1976)) and the mass flow rate is consequently determined. Main input parameters are summarized in Table 3. 1.
The economic analysis is based on the Eq. 1-Eq. 4. The parameters of the dryer are extrapolated by manufacturers data. The total investment cost, J_{tot}, is the sum of the costs of drilling, J_{well}, heat exchangers, J_{AirHE}, ORC, J_{ORC}, and dryer, J_{Dryer}. For drilling

a depth of 400m is considered. The operation and maintenance costs are supposed to be 2.00% of the total investment cost. The revenues, R, in the Simple PayBack, SPB, equation, Eq. 4, derive from the reduction of sludge to be disposed, m_{sl}, and the electrical energy self-production, E_{el}. A specific cost of 250 €/ton for avoided sludge disposal, c_{sl}, and 180 €/MWh of electricity purchase, c_{el}, are considered.
As regards the environmental analysis (Eq. 7-Eq. 9), the avoided Primary Energy, ΔPE, is calculated as the annual electricity consumption, E_{el}, divided by the average efficiency of the thermo-power plants, η_{TPP}, actually installed in Pantelleria Island. Consequently, the avoided primary source, ΔPS, and the avoided CO_2 emissions, ΔCO_2, are trivially calculated considering the Lower Heating Value (LHV) and the Emission Factor (EF) (ISPRA 257/2017) of diesel gasoline engines.

Table 3. 1 Main design parameters of simulation models

<table>
<tr><th>Sludge</th><th></th><th colspan="3">ORC</th><th></th></tr>
<tr><td>Mass flow rate $\dot{m}_{sl}$</td><td>70.0 kg/h</td><td colspan="3">Nominal power $\dot{P}_{ORC}$</td><td>25.0 kW</td></tr>
<tr><td>Moisture content $MC_{sl,1}$</td><td>75.0 %</td><td colspan="3">Turbine isentropic efficiency η_{turb}</td><td>75.0%</td></tr>
<tr><td>Inlet temperature $T_{1,sl}$</td><td>20.0 °C</td><td colspan="3">Pump isentropic efficiency η_{pump}</td><td>65.0%</td></tr>
<tr><td>Hot air</td><td></td><td colspan="3" rowspan="2">Pinch point temperature difference at the evaporator $\Delta T_{pinch,eva}$</td><td rowspan="2">5.00 °C</td></tr>
<tr><td>Mass flow rate $\dot{m}_{air}$</td><td>0.60 kg/s</td></tr>
<tr><td>Inlet temperature $T_{air,1}$</td><td>20.0 °C</td><td colspan="3" rowspan="2">Pinch point temperature difference at the condenser $\Delta T_{pinch,cond}$</td><td rowspan="2">5.00 °C</td></tr>
<tr><td>Outlet temperature $T_{air,2}$</td><td>120 °C</td></tr>
<tr><td>Geo-fluid</td><td></td><td colspan="3">Cooling water inlet temperature $T_{CW,1}$</td><td>18.0 °C</td></tr>
<tr><td>Mass flow rate $\dot{m}_{geo}$</td><td>1.00 kg/s</td><td colspan="3">Cooling water outlet temperature $T_{CW,2}$</td><td>26.0 °C</td></tr>
<tr><td>Inlet temperature $T_{geo,1}$</td><td>160 °C</td><td colspan="3">Dryer</td><td></td></tr>
<tr><td>Inlet pressure $P_{geo,1}$</td><td>8.00 bar</td><td colspan="3">Length</td><td>6.00 m</td></tr>
<tr><td colspan="6">ORC Evaporator (TEMA BEM, 45°Rot.Sqr, 1 Tube passes; Titanium)</td></tr>
<tr><td>Tube outlet diameter/pitch</td><td>19.1/23.8 mm</td><td>Tube lenght</td><td>1.80 m</td><td>Tube /tickness</td><td>2.00 mm</td></tr>
<tr><td colspan="6">ORC Condenser (TEMA BEM, 45°Rot.Sqr, 1 tube passes; Carbon Steel)</td></tr>
<tr><td>Tube outlet diameter/pitch</td><td>19.1/23.8 mm</td><td>Tube lenght</td><td>1.80 m</td><td>Tube /tickness</td><td>2.00 mm</td></tr>
</table>

$$J_{well} = 2 \cdot 1000 \cdot \text{Depth} \qquad \text{Eq. 1}$$

$$J_{AirHE} = 150 \left(\frac{A_{AirHE}}{0.093} \right)^{0.78} \qquad \text{Eq. 2}$$

$$J_{ORC} = 4.00 \cdot 10^3 \cdot \dot{P}_{ORC} \qquad \text{Eq. 3}$$

$$SPB = \frac{J_{tot}}{R_{sl} + R_{el}} \qquad \text{Eq. 4}$$

$$R_{sl} = c_{sl} \times m_{sl} \qquad \text{Eq. 5}$$

$$R_{el} = c_{el} \times E_{el} \qquad \text{Eq. 6}$$

$$\Delta PE_{[MWh]} = E_{el,[MWh]} / \eta_{TPP}; \ \eta_{TPP} = 0.390 \qquad \text{Eq. 7}$$

$$\Delta PS_{[ton]} = \frac{E_{el,[MWh]} \cdot 3.6}{LHV}; \ LHV = 44.4 MJ/kg \qquad \text{Eq. 8}$$

$$\Delta CO_{2,[MWh]} = \Delta PS_{[ton]} \times EF; \ \ EF = 3.11 \qquad \text{Eq. 9}$$

4. Results and discussion

In Table 4. 1 and Table 4. 2 the main results of the thermodynamic analysis and the geometrical features of the heat exchangers are respectively reported.
One of the most important aspect is that only 1.00 kg/s of geothermal source at 160 °C is suitable to feed all this small scale system, capable to dry 70.kg/h of sludge at a final moisture content of 6.31%. Moreover, temperature of geo-fluid before being rejected is significantly above the 70.0°C, limit temperature to avoid excessive scaling and deposition phenomena and depletion of geothermal reservoir. The ORC supplies 25 kW of net power output, used to feed the dryer and the wastewater treatment systems, as mentioned in System layout section, showing a first law efficiency equal to 9.84%: this is a satisfactory value considering the thermal source temperature and the low capacity.

Table 4. 1 Results of thermodynamic analysis

Sludge		**ORC ($\dot{m}_{R245fa}$ =0.88 kg/s)**			
Moisture content $MC_{sl,2}$	6.31 %	Turbine electric power output $\dot{P}_{turb}$			26.0 kW
Outlet temperature $T_{2,sl}$	67.0 °C	Pump electric power input $\dot{P}_{pump}$			1.00 kW
Desiccant flow		p_1=1.81 bar	T_1 = 30.8 °C	satured liquid	
Mass flow rate $\dot{m}_{df}$	1.74 kg/s	p_2=15.4 bar	T_2 = 31.8 °C	subcooled liquid	
Inlet temperature $T_{df,1}$	78.0 °C	p_3=15.3 bar	T_3 = 109 °C	satured vapour	
Outlet temperature $T_{df,2}$	57.0 °C	p_4=1.84 bar	T_4 = 59.0 °C	superheated vapor	
Geo-fluid		Evaporator thermal power			213 kW
Temperature $T_{geo,2}$	146 °C	Condenser thermal power			188 kW
Pressure $P_{geo,2}$	7.95 bar	Cooling water mass flow rate $\dot{m}_{CW}$			5.50 kg/s
Temperature $T_{geo,3}$	96.0 °C	**Air HE**			
Pressure $P_{geo,3}$	7.92 bar	Thermal power			60.4 kW

Table 4. 2 Heat exchangers geometrical features

	ORC		**Air HE geometrical feature**	
Geometrical feature	**Evaporator**	**Condenser**	Type	Standard axial flow
Shell diameter	54.0 cm	60.0 cm	Core length	58.5 cm
Tube number	360	448	Core width	42.2 cm
Number of baffles	14.0	2.00	Core depth (stack height)	10.0 cm
Baffle spacing	11.0 cm	36.0 cm	Number of layer per exchanger	15

Table 4. 3 Economic and environmental analysis

J_{well}	800 k€	R_{tot}	146 k€/year
J_{AirHE}	2.28 k€	SPB	10.1 year
J_{ORC}	100 k€	Avoided sludge	450 ton/year
J_{Dryer}	350 k€	Avoided electricity	75 MWh/year
J_{tot}	1.28 M€	Avoided primary energy	192 MWh/year
R_{sl}	112 k€/year	Avoided primary source – Diesel gasoline	15.6 ton/year
R_{el}	13.5 k€/year	Avoided CO_2 emissions	48.5 ton/year

Table 4. 3 shows the results of the economic and environmental analyses. The high investment cost and consequently the related high SPB could be mitigated by increasing the scale factor of the whole plant. In addition, the geo-fluid could be

further exploited to pre-heat the desiccant current before reinjection. Despite this, the system reduces the sludge disposal from 613 to 164 ton/year, with a saving of electricity and economic resource. Considering the specific case study of Pantelleria, the electricity self-produced by the ORC corresponds to 192 MWh/year of saved primary energy, then to 15.6 tons/year of diesel gasoline and 48.5 tons/year of avoided CO_2 emissions.

5. Conclusions

In this paper, the thermodynamic, economic and environmental analyses of a small scale system is presented. Such plant is composed of a wastewater sludge dryer coupled with an ORC powered by geothermal energy. The analysis is carried out for the case study of Pantelleria island. The system allows to reduce the transportation and disposal from 613 to 164 ton/year of sewage sludge. Despite the high value of Simple PayBack, with 25 kW of geothermal energy, the electrical energy demand of wastewater treatment plant, sludge dryer and geo-fluid pumping, can be supplied by the ORC, avoiding 15.6 tons/year of diesel gasoline and 48.5 tons/year CO2 emissions.

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Thermodynamic and economic analyses of a combined CHP system fuelled with rice husk

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Abstract

Nowadays, the extensive annual rice production, especially the one related to the Asian market, makes available enormous quantities of rice husk, a residual biomass suitable for being used for energy conversion. The drying process of the rice production chain requires great amounts of thermal and electric energy, which is currently strongly incentivizing manufacturers to adopt new and efficient systems of rice processing. In this paper, a combined Cooling Heat and Power (CHP) system fuelled with rice husk is proposed and analyzed by the thermodynamic and economic point of views. A gasification process allows to produce simultaneously heat and syngas: hot syngas is first exploited through a heat exchanger to heat the air sent to the rice husk dryer unit and then opportunely cooled and cleaned before powering a cogenerative Internal Combustion Engine (ICE) unit (top cycle), which produces power to be fed into the grid. The gasifier is fed with the rice husk coming from the dryer. The exhaust gases of the ICE are exploited to also preheat the air for the drying process. The cooling water is instead used within an Organic Rankine Cycle (ORC) (bottom cycle) to produce the power covering the internal demand of electricity. The configuration is calibrated basing on a case study of a rice manufacturer of Taiwan and modeled in the Thermoflex^{TM} environment. Design of heat exchangers is made in Aspen Plus.

Keywords

Rice Husk, Gasification, Internal Combustion Engine, Organic Rankine Cycle

1. Introduction

The last few years have been characterized by a great interest on Combined Heat and Power (CHP) plants fuelled with biomass. This technology is emerging on the market with promising prospects for the near future, such as new perspectives for residue biomass utilization in district heating&cooling and/or in industrial-commercial activities. An interesting CHP application is a gasifier coupled with an Internal Combustion Engine (ICE) with possible waste heat recovery (WHR) through Organic Rankine Cycle (ORC). While energy saving and the environmental benefits of this kind of power plants are undoubted, technological obstacles still remain, affecting their large diffusion. Systems with low price and easy-to-use operation for industrial and residential end-users are still actually under development. Future introduction of micro and small CHP plants for domestic/commercial applications will depend on the available technology, on the capability to match the electrical and thermal loads, and the gas and electricity prices. These economic and technical uncertainties curb the diffusion of micro and small CHP plants at the moment, especially in countries where economic incentives are not yet provided for bio-energy.

The present study is focused on a CHP system consisting of a gasifier fuelled with rice husk coupled with an ICE (top cycle), whose cooling water powers an ORC (bottom cycle). The gasifier is based on a thermo-chemical process which converts biomass through partial oxidation into a fuel gaseous mixture (syngas), mainly consisting of H_2, CO, CH_4, CO_2 and N_2. The syngas needs to be cleaned in order to remove tars and inorganic compounds before being sent to the ICE. The heat to electric output ratio of an ICE is typically 2:1.
ORC is a commercially available system for biomass utilization (Triogen, 2017), with good conversion efficiencies (Strzalka et al., 2010), especially at electric powers lower than 1 MWe (Quoilin et al., 2013). Typical working fluids employed are pentane, n-pentane, siloxane, R134a, Toluene and R245fa, which is more suitable for temperature up to 160 °C (Calise et al.,2014)
The electrical output of small scale ORC systems is in the range of 20-160 kW_e. Main typical thermodynamic characteristics of such systems are summarized in Table 1.1.

Table 1.1: Main thermodynamic characteristics of gasifiers coupled with ICEs fuelled with biomass (Frigo, (2014).

Thermodynamic characteristics	Gasifiers + ICEs	ORCs
Specific biomass consumption(humidity 40 %) [kg/kWhe]	1.2-1.7	2.5-3.5
Electric efficiency % [-]	~ 25	~ 12
Thermal efficiency % [-]	~ 25	~ 70
Heat temperature available [°C]	80-500	30-80
Operation time [h/y]	7000	8000
Specific Cost [€/kWe]	3000-5000	5000-7000

Actually, the specific ORC investment cost, ranging between 1.10 k€ and 7.40 k€, strictly depend of the kind of project (layout complexity, power output) and on the specific thermal resource to be exploited (Lemmens, 2016).

2. System layout and simulation model

The here considered CHP system fuelled with syngas from the gasification of rice husk is analyzed with Thermoflex™, a thermal engineering software usually employed by power and cogeneration industries. Thermoflex™ owns a broad library of working mediums (gases, fuels, refrigerants, etc.) and, both pre-built and user-customized commercial power plants, as gas turbines and internal combustion engines. ICEs in Thermoflex™ are supposed to be natural gas fuelled spark ignition: each pre-built model is characterized by default values of power output, electrical efficiency, hence fuel power input, and flue gas mass flow rate. Therefore if the engine is fed with a low Lower Heating Value (LHV) fuel instead of methane, and thus a higher mass flow rate of this fluid is required, the software automatically lowers air input to compensate that increase and keeps gas mass flow rate constant, always yielding the same power with the same efficiency. This last is a quite strong assumption, as demonstrated by Costa et al. (2017). Therefore, a customized ICE model in Thermoflex has been preferred as it gives the possibility to evaluate the variation of power output with the primary energy content given by the fuel, thus it is supposed to be more adequate to the scope of the present work.
Based on the assumption of Carrara (2010), that both in the case of natural gas and syngas feeding, a certain size internal combustion engine (in terms of power output) is roughly characterized by the same gas mass flow, methane-fed ICEs models can be suitably used to assess the performance in case of syngas fuelling.

The considered layout of the here analyzed system is shown in Figure 2.1. Dried biomass and air enter the gasifier; the raw syngas is cleaned through a scrubber and a separator before fuelling the ICE. Before the cleaning, the syngas temperature is decreased (down to 350°C) and the sensible heat transfer is used to warm up the air for the drying section, HE1. Since syngas fuel is not enough to heat the air for the drying process of the indicated mass flow rate of rice by the Taiwanese plant owner, another heat exchanger is employed to recover heat from the exhausts exiting the ICE, HE2. Both the HE1 and HE2 are co-axial plate-fin compact heat exchangers. Pressure drop are neglected in both the exchangers.
The ICE cooling circuit is used as hot source in the evaporator for the ORC. R245fa is used as working fluid. Cooling water temperature variation is fixed from 82°C to 92°C, as well as the pressure levels, (8 bar for the evaporation and 2.5 for condensation). The cooling water at the condenser varies between 20°C and 30°C. The generator efficiency is fixed at 95%.

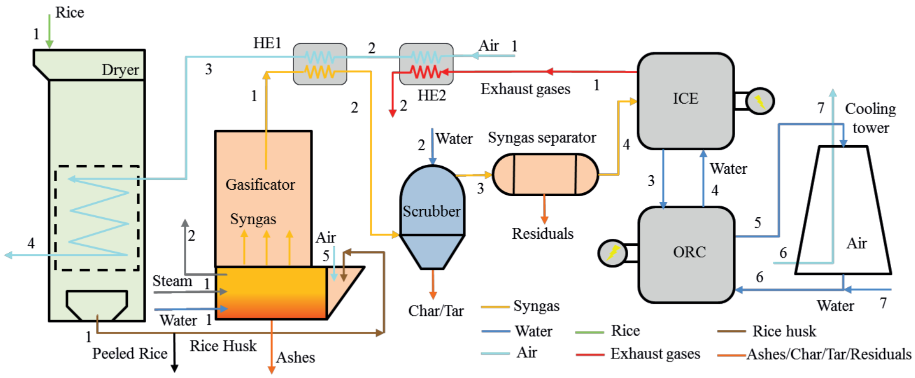

Figure 2.1: System layout.

Biomass feeding the gasifier is generally pre-treated by a drying process, aimed at reducing the initial moisture content of the biomass. This increases the conversion efficiency of gasification, leading to a gaseous syngas with higher LHV content. However, in this analysis the drying system is not simulated: a fixed desiccant current equal to 450 m^3/min at a minimum temperature of 120°C is supposed to dry 9000 kg/h of paddy, with an initial moisture content of 26%. This allows feeding the gasifier with a constant flow rate of 0.5 kg/s of rice husk biomass, with 15% of moisture content. The operative equivalence ratio of the gasifier is equal to 0.3, as it is a classical condition for gasification. The biomass composition in terms of ultimate and proximate analysis, as derived by the Thermoflex model, is shown in Table 2.1.

Table 2.1: Biomass ultimate and proximate analysis in dry basis (db) and dry ash free basis (daf).

	db % [w/w]	daf % [w/w]
VM (Volatile Matter)	54,40	68,51
FC (Fixed Carbon)	25,00	31,49
A (Ashes)	20,60	-
C	31,44	39,60
H	4,76	6,00
O	42,64	53,70
N	0,56	0,70
LHV (Lower Heating Value) [MJ/kg]	12,36	15,57
HHV (Higher Heating Value) [MJ/kg]	13,40	16,80

The model of gasifier used for the present layout needs the solid biomass and oxidizer air as input, while the raw syngas composition, temperature of gasification and the slag (this last composed of residual charcoal and ashes) are the main outputs. The reliability of the gasifier model chosen in Thermoflex is preliminarly assessed considering different initial biomasses, such as rubber wood (Jayah et al., 2003), treated wood (Ptasinski et al., 2007) and sawdust (Altafini et al., 2003)), and by comparing the syngas composition obtained for an equivalence ratio of 0.3 to experimental measurements and numerical results obtained using an optimized 0D thermo-chemical equilibrium model developed and validated by Costa et al. (2015). Details about the biomass ultimate and proximate analyses may be found in Costa et al. (2015), while results of the comparison in terms of species volumetric fraction and gasification temperature are reported in Figure 2.2. The simulation results in Thermoflex™ refer to full-load steady conditions.
Once the system is analysed by the thermodynamic point of view, a detailed designing of all the heat exchangers (HE1, HE2 and the ORC evaporator and condenser) is performed in Exchanger Design&Rating environment of AspenOne platform.
The profitability (Eq. 1-Eq. 5) of the system is assessed by estimating the Simple PayBack, expressed by the ratio between the total investment cost J_{tot} and the sum of operating costs and economic savings, once a traditional biomass butch dryer is considered as referring technology. The total investment cost is trivially given by the sum of the dryer cost J_{Dry} (De Fusco et al., 2015), of the gasifier-ICE group cost $J_{Gas.+ICE}$, the ORC cost J_{ORC} and the heat exchangers HE1 and HE2, J_{HE} (Buonomano et al., 2014). The yearly economic savings are represented by the sum of the revenue $R_{el,sell}$ related to the selling of net electricity supplied ($E_{el,net}$), to the avoided cost of electricity purchase, $R_{el,av.purch.}$, to the avoided cost of thermal energy of the desiccant current $R_{th,av.}$, and to the avoided cost of rice husk disposal $R_{disp,av.}$ The yearly operational costs are given by the Operation&Maintenance costs $C_{O\&M}$ (assumed as the 5.00% of the total investment cost) and by the cost of ash disposal $C_{ash,disp.}$ Parameters used in the analysis are reported in Table 3.2.

$$SPB=\frac{J_{tot}}{R_{el,sell}+R_{el,av.purch}+R_{th,av.}+R_{disp,av.}-C_{O\&M}-C_{ash,disp}} \quad \text{Eq. 1}$$

$$\begin{cases} J_{tot}=J_{Dry}+J_{Gas.+ICE}+J_{ORC}+J_{HE} \\ J_{Gas.+ICE}=\dot{P}_{nom.ICE}\cdot c_{Gas+ICE} \\ J_{ORC}=\dot{P}_{nom.ORC}\cdot c_{ORC} \end{cases} \quad \text{Eq. 2}$$

$$R_{el,sell}=E_{el,net}\times c_{sell} \quad \text{Eq. 3}$$

$$R_{el,av.purch}=E_{selfcons}\times c_{puch} \quad \text{Eq. 4}$$

$$\begin{cases} R_{disp,av.}=m_{husk}\cdot c_{disp.husk} \\ C_{disp,ahs.}=m_{ash}\cdot c_{disp.ash} \end{cases} \quad \text{Eq. 5}$$

Table 2.2: Main parameters of the economic analysis.

Specific cost of gasifier+ICE $c_{Gas+ICE}$	3500 €/kW	**Specific cost of natural gas $c_{nat.gas}$**	0.400 €/Sm^3
Specific cost of ORC c_{ORC}	4000 €/kW	**LHV natural gas**	34.5 MJ/ Sm^3
Incentive price of electricity (DM 06/2016) c_{sell}	0.14 €/kWh	**Specific disposal cost of ash $c_{disp.ash}$**	100 €/ton
Purchase price of electricity c_{purch}	0.06 €/kWh	**Yearly hours of operation**	2080 h
Specific disposal cost of rice husk $c_{disp.husk}$	200 €/ton	**Conventional combustion chamber efficiency η_{CC}**	97.0%

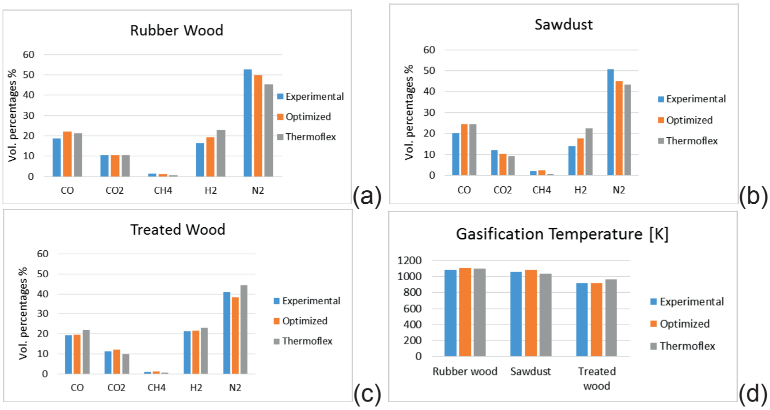

Figure 2.2: Comparison between experimental measurements, numerical results of both the optimized equilibrium model and the Thermoflex^{TM} model in terms of volumetric syngas compositions for a) rubber wood, b) sawdust, c) treated wood and d) gasification temperature.

3. Results and discussion

After the validation, the model is used to estimate raw syngas composition, syngas lower heating value and gasification temperature of the rice husk.

A cleaning section downstream the gasifier is generally present in the majority of the classical real configurations. However, the produced syngas exiting the gasifier is actually modelled as already clean, being composed only by CO, CO_2, CH_4, H_2, N_2 as shown in Table 3.1. Thus, the devices dedicated to syngas cleaning are considered to evaluate the correct power consumption of the whole system and, in case of scrubbing, determine a syngas moisture variation (which is always completely removed at the end of the treatment chain).

The ICE power output is 1150 kWel with an electrical efficiency equal to 27.96%. The heat recovery allows the air for the dryer to reach a final temperature of 124 °C. As regards the ORC, it produces 76,3 kWel and it works with a thermal efficiency equal to 6.5% that remains unchanged by varying the ICE power output, since the specific enthalpy variations are constant and only the mass flow-rate changes.

Finally, a parametric study is proposed with respect to the power output by the engine and the ORC, varying the equivalence ratio of the gasifier in the range of 0.2 ÷ 0.4, and by keeping constant the biomass flow rate, the dryer air flow rate and the ORC operative parameters. The main results of the parametric analysis are shown in Figures 3.1.

Table 3.1: Syngas species composition on daf basis obtained from rice husk gasification.

	% [v/v]	% [w/w]
CO	22,58	26,84
CO_2	13,76	25,71
H_2	25,58	2,2
CH_4	0,0006	0,0004
N_2	38,07	45,26

As the equivalence ratio of the gasifier increases, a reduction of CH_4, H_2 and CO is achieved (Figure 3.1.a), leading to a reduction of the related syngas LHV and to an increase of the gasification temperature (Figure 3.1.b), due to the operative conditions that are approaching the stoichiometric one. This reflects on the useful power of the ICE that reduces due to the lower primary energy content of the syngas, as well as on the thermal energy of the exhaust gases.

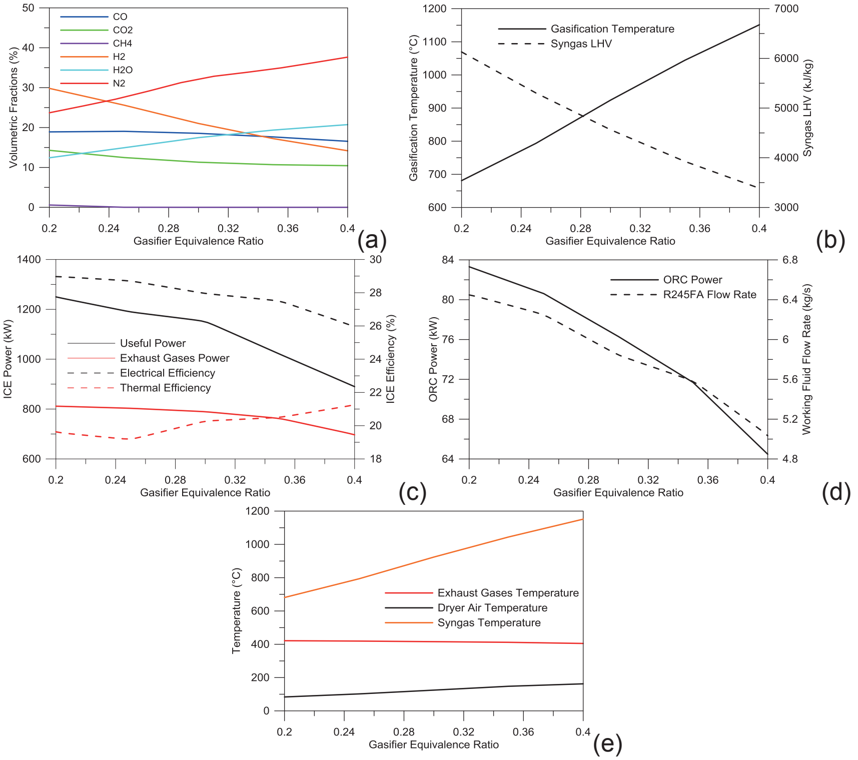

Figure 3.1: Trends as a function of the gasifier equivalence ratio of a) syngas species composition, b) gasification temperature and syngas LHV, c) ICE useful and thermal power, and ICE electrical and thermal efficiency, d) ORC power output and working fluid flow rate, e) exhaust gases, syngas and air dryer temperatures.

However, the reduction of the ICE electrical efficiency is accompanied by an increase of the thermal energy content of the exhaust gases (Figure 3.1.c). The ORC system, working at the same efficiency, produces less electrical power as the gasifier equivalence ratio increases, due to a reduction in the flow rate of the working fluid (Figure 3.1.d). Finally, in Figure 3.1.e the comparison of the fluid temperatures is reported. The air that is supposed to enter the dryer increases from 83.5 °C to 162.4 °C thanks to the heat transfer that occurs in the two heat exchangers: the increase in the syngas temperature has a stronger effect with respect to the slight reduction that occurs in the exhaust gases energy. For the sake of brevity, only the design of the HE1 and HE2 are reported in Table 3.3, while in Table 3.4 the main results of economic analysis are presented for an Equivalent Ration equal to 0.3.
As reported, the SPB calculated amount to 5.32 years, which can be considered competitive.

Table 3.3: Design parameters of HE1 and HE2 heat exchangers.

Geometrical feature - Standard axial flow – (Gasifier E.R.=0.3)	**HE1**	**HE2**
UA	1.60 kW/K	0.7 kW/K
Heat transfer area	189 m^2	88.7 m^2
Core length	84.1 cm	210 cm
Core width	114 cm	106 cm
Core depth (stack height)	63.3 cm	60.3cm
No. of layer per exch.	63	60

Table 3.4. Main results of economic analysis (Gasifier E.R. = 0.30)

Investment costs	J_{Dry}	$J_{Gas.+ICE}$	J_{ORC}	J_{HE}	J_{Tot}	**SPB**
	494 k€	4.03 k€	305 k€	88.7 k€	4.91 M€	5.32
Yearly revenues	$R_{el,sell}$	$R_{el,av.purch}$	$R_{th,av}$	$R_{disp,av}$	R_{Tot}	
	347 k€	4.37 k€	90.6 k€	734 k€	1.13 M€	
Operational costs	$C_{O\&M}$	$C_{ash,disp}$		C_{Tot}		
	246 k€	7.49 k€		253 k€		

4. Conclusions

The CHP system fuelled with syngas from the gasification of rice husk is analyzed from a thermodynamic and economic point of view. A parametric study of the power output of both the ICE and the ORC is performed as a function of the increasing equivalence ratio of the gasifier, showing a reduction of the electric efficiency of both the systems, and an increase of the thermal efficiency of the ICE, this last employed to warm up the air that is supposed to enter the drying system. The SPB amounts to 5.32.

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A real non-pseudo spatial index for neutral CO2 for urban nano-zones in temperate continental climate

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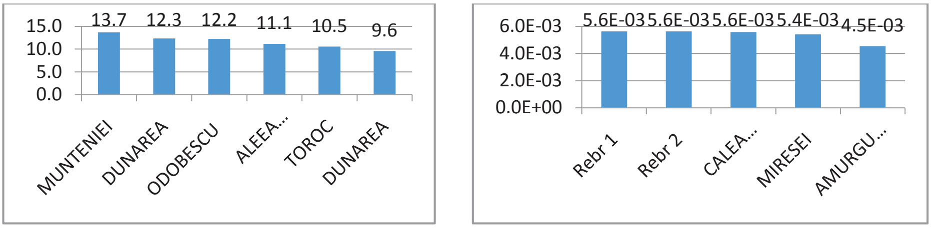
The cities start to become vulnerable to climate change (EEA, 2015). Some cities started two decades ago to do the green inventory (Ciupa, 2015). Some current climate models or measurement are grossly misleading (Stern, 2016) We measure the flows O2 and CO2 emission for the street of Timisoara. The streets and segment of streets are considered as nano-zones and can be noticed as partial Roegenian processes. The main figures are extracted from (Ciupa, 2005), PMT (PAED, 2014), City Hall Database (to see footnote 1, map T03 for vehicle flows)[1]. For metrics of O2, C and C(O2) potential to be sequestrated, the transformation coefficients are at half-level from US report average value [2]. We built a spatial index (ratio) for the indirect relation between CO2 emissions of vehicle in Timisoara and the equivalent in CO2 of O2 productivity by the tree crown.

Fig.1 The highest (left) and lowest (right) index values for 268 main streets, 2010, Timisoara



The regression between the trees Roegenian fund (the crown) and CO2 vehicle emissions (vem) daily is next:CO2 vem = 0.0649*The crown volume + 466.56. It was tested 268 streets and street segments. The F test value is 8.35 and R2 coefficient is 0.03. The T Student test values are: 2.89 for coefficient and 7.98 for constant. The index reveals us the amplitude for the main streets from the city Timisoara. The calculations use a simple coding which fulfill the Roegenian test for pseudo-measures. The figures index for main streets range between 13.7 and 0.0045. Calculations assure the decision support for urban infrastructure development.

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Development of air manifold for a straw–fired batch boiler using experimental and numerical methods

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Abstract

Air manifolds are used in straw-fired batch boilers to provide appropriate excess of air as well as homogeneous air distribution in primary and secondary combustion chambers. The paper presents the results of variant analysis of the operation of the air manifold responsible for providing air for the combustion process in the biomass-fired batch boiler. A test stand including a set of velocity sensors has been built to analyze the operation of the air manifold. The results of the experiments were implemented in a computational fluid dynamics model, which allowed to determine the elements of the manifold structure that are crucial from the point of view of efficient combustion and acceptable level of fan's energy consumption. The following stage of the studies encompassed the development and modeling of a new design of the manifold. The results of the studies and recommendations for designing air manifolds have been presented.

1. Introduction

The combustion of straw in modern batch boilers proceeds in two stages: in the primary combustion chamber and the secondary combustion chamber. During the first stage, gasification of the fuel in the primary chamber takes place under controlled air deficiency (to increase the efficiency of straw gasification). Combustible gaseous products of the first stage flow into the secondary chamber, where the post-combustion occurs. It is crucial to provide sufficient distribution of air in the areas of the two combustion chambers mentioned above. The boiler system is equipped with an air supply system, which uses a centrifugal fan and an air manifold (Figures 1-a, 1-b). More detailed information concerning the boiler may be found in [Szubel M. 2015, Szubel M., Adamczyk W., Basista G., Filipowicz M. 2016]. A lot of attention is given to understanding the phenomena occurring in the secondary combustion chamber, which are directly related to the formation and emission of the most undesirable pollutions, such as carbon monoxide (CO) or particulate matter (ash and non-combusted fuel particles, tar, etc.). One of the basic ways to improve the efficiency of the combustion in the secondary chamber is to optimize the design and the algorithm of the operation of the air feeding system. This can be carried out through experimental works and numerical simulations [Buchmayr M., Gruber J., Hargassner M., Hochenauer C., 2016].

2. Goal of the study

The study described in the paper constitutes a part of a project aimed at the improvement of selected operation aspects of a newly designed straw-fired boiler. The air distributor of the examined boiler consists of four ducts, welded to the front of the main duct (body). A series of four parallel ducts are connected to the area of the primary combustion chamber. Additional two ducts fixed on the back wall (visible in

Figures 1-a, 1-b) are responsible for feeding the air to the secondary combustion chamber. In comparison with other state of the art straw-fired batch boilers, the applied secondary air feeding system (Figure 1-c) is more advanced – three secondary air injection points are located on the left and right walls of the secondary combustion chamber.

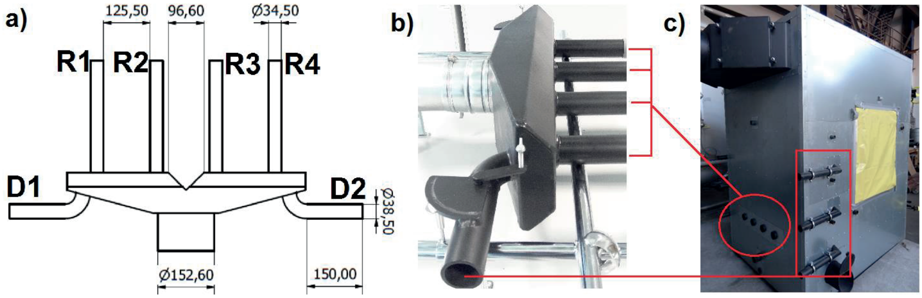

Figure 1. Projections of the studied air manifold (top view): (a) picture of the actual air manifold and (b) the location of the connectors in the boiler, (c) primary air nozzles marked with a circle and one (on the left side wall) of the two series of secondary air nozzles, marked with a rectangle.

Due to the complex design of the air distribution system it is necessary to obtain detailed information regarding the operation of the air manifold. Knowledge of the impact of the geometry of this element of the system on the air distribution in the manifold outlets is significant in terms of achieving efficient and homogenous oxidant penetration of the combustion chamber. Based on this, the main goal of the study has been defined as the experimental and numerical description of the phenomena occurring during the operation of the system. Consequently, the achievement of improved distribution of air manifold outlets became a matter of consideration. This was carried out by the development of a modified structure of the air distribution system. Procedures and methods used in the study have been described in further sections of the paper.

3. Methodology

3.1 Experiment

Experimental studies of selected operating parameters of the state of the art air manifold were carried out at a dedicated test stand designed and constructed by the authors of this paper. The stand (Figure 2) consisted of an air manifold equipped with a set of additional outlet ducts (PCV) allowing for the installation of measuring instruments, as well as a supply duct, which enabled the inlet conditions to be tested and allowed for an efficient supply of the air stream from a centrifugal fan. The change of the air velocity at the inlet was performed by means of a throttle.

In the measurements, thermoanemometers with a 0 - 10V DC analog output and a range from 0 to 20 m/s were used. The readouts from the thermoanemometers, mounted before the inlet of the manifold and on a selected outlet duct, were made by means of the developed measurement-control module, which was also responsible for the control of the throttle position and the fan efficiency. The module was constructed based on programmable PLC controllers.

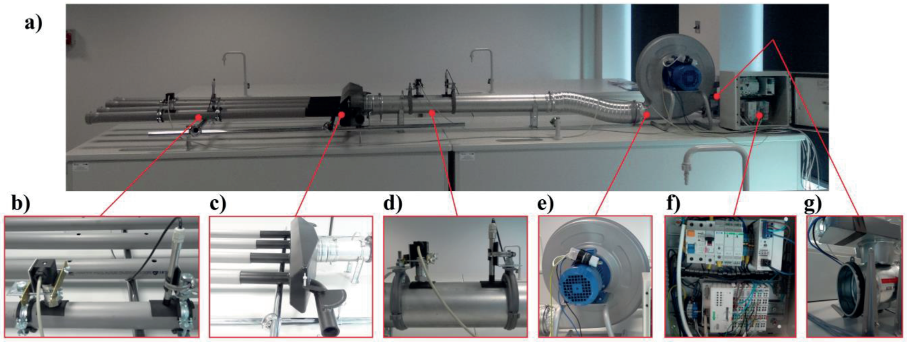

Figure 2. The test stand (a) and selected components: b) the outlet measurement set, c) the examined air manifold, d) the inlet measurement set, e) the centrifugal fan, f) the applied automation, g) the throttle.

1.2 Preparation of the CFD model

The numerical CFD models of the air manifold have been prepared in the ANSYS Workbench (ANSYS Fluent 17 solver) environment. Cut-Cell method of meshing was applied to generate the computational grid. Advanced sizing functions were used to obtain satisfactory mesh quality indicators. The inflation layer has been created using the First Layer Thickness algorithm. The maximum size of the mesh control volume was 3 mm (determined by the sensitivity analysis of the mesh). The total number of grid nodes was 1456 000. The lowest value of the mesh orthogonal quality was 0.1, which is a fully acceptable value [ANSYS Fluent 2015].

Inlet boundary condition (inlet of the duct connecting the fan and the manifold) was defined as Velocity. All outlets of the manifold were defined as Pressure Outlets. Gauge pressure at the outlet in relation to the pressure in the domain was set to 0 Pa. SIMPLE, segregated scheme of the Pressure – Velocity Coupling was selected for the calculation. In case of equations of momentum, pressure and turbulence model, the Second Order Upwind advection scheme was applied. To find the best agreement between the experimental and numerical results, a CFD model was solved with the implementation of three different turbulence models: (i) k-ε Realizable (with scalable wall functions), (ii) k-ω and (iii) SST k-ω.

4. The results of the experiment, CFD analysis and the optimization of the air manifold

A compilation of the selected results of experiments carried out on the test stand and data obtained based on the CFD simulation for the applied turbulence models has been presented in Figure 3. Curves created for the purposes of the experiment include error bars related to the accuracy of the applied sensors.

Points in the charts representing the results of the experiment were charted based on averaged values from three measurement series. It was found that there is a slight asymmetry between the left and the right side of the air manifold, which resulted in different measurements of velocity on analogous outlets. This situation may have been related to the manufacturing precision of the air distributor in industrial conditions, but also to some small asymmetries of throttles installed in the secondary air ducts D1, D2 (shown in Figure 1-b) as well as a slight deviation from the normal position of the fan connection pipe and the manifold on the test stand. However, in case of the CFD model, the air manifold has to be considered as a fully symmetrical element.

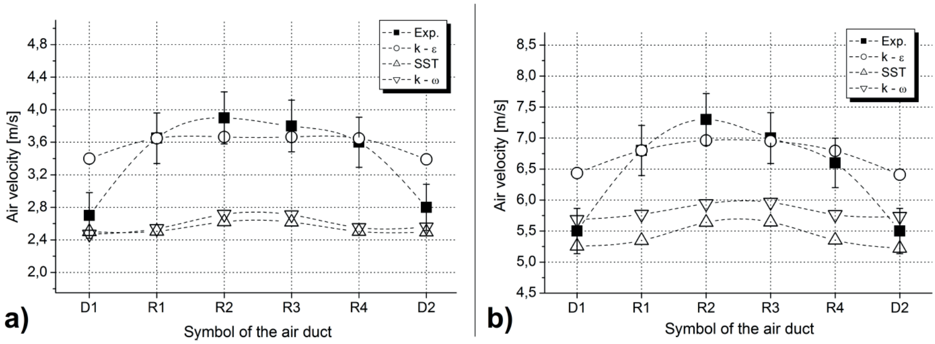

Figure 3. The comparison of results of the experiment and the CFD modelling for selected degrees of the throttle closing with different approaches to the simulation of the turbulence. R1 – R4 – primary air ducts, D1, D2 – secondary air ducts (see Fig. 8). Throttle closing in the given examples: a) 70%, b) 65%, c) 60%, d) 55%.

It has been noted that for each studied throttle closing degree, the k-epsilon turbulence model provides the best agreement with the experimental data regarding the velocity on primary air outlets. The results of computations using the two other turbulence models provided rather satisfactory values for the secondary air outlets. Such a situation confirms the direct relation between the accuracy of the computations made using the selected turbulence model and the y+ value. In regions of the secondary air ducts, the calculated y+ value was always lower than 0.6, while in case of four front ducts, the parameter reached its maximum values (especially close to the inlets from the main perpendicular duct) - exceeding 1.15.

As a general result of the performed analysis, high heterogeneity of air velocities in subsequent outlets of the air manifold has been noted. Outlet velocities are directly related to the distance of the given duct from the air inlet. In case of the secondary air nozzles, an additional factor influencing the outlet parameters is the geometrical configuration of ducts – the ducts were situated on the rear wall of the manifold's main body and kinked to the left and to the right side.

Figure 4-a shows the proposed change in the design, which, in case of the study in concern, consisted in bending the main duct, which results in the change of length of the primary air ducts (the total length of the air distributor had to be preserved due to the functional aspects of the operation of the entire boiler system). A modification that

was equally significant was the application a cylindrical collector's body, also comprised of two ducts. In practice, this may be easily achieved by welding, and it is not required to use additional machines, such as a bender, as in the case of a standard manifold. Moreover, the locations and the design of secondary air outlets were modified. The outlets were connected with the air manifold via conical diffusers.

The numerical 2D model of the prototype was created based on the knowledge gained during the development of the model of the standard version of the air manifold. In case of the new design, the "α" bend angle of the manifold was parameterized. Due to the requirement to preserve the length of the primary air ducts sufficient to install the prototype in the boiler, parametric analysis was carried out for the bend angle values between 90˚ and 120˚. Figure 4-b presents the changes of air velocities in outlet ducts, depending on the bend angle of the manifold body. A significant change in the characteristics of the parameter distribution was found especially in the case of the secondary air ducts, where the new values were the highest in the entire system. It is also clearly visible that an increase in velocities and mass flow rates in external (R1 and R4) primary air ducts is proportional to the increase of the bend angle. Due to the exceptionally promising results obtained during the described parametric analysis, it was decided to extend the model of the prototype to a fully three-dimensional CFD case with an α = 120˚.

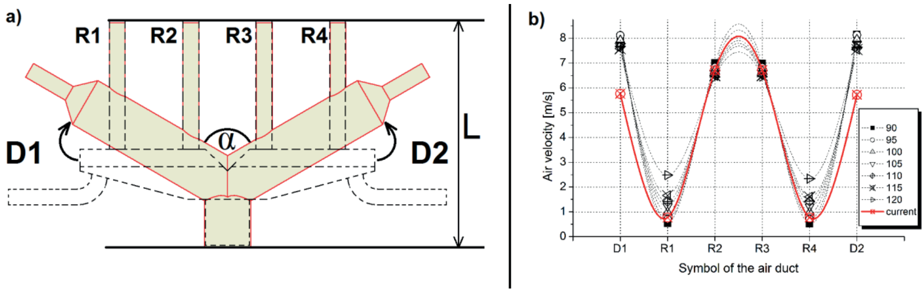

Figure 4. Proposed design of the prototype of the air manifold (a) and changes of the velocity on outlets from the manifold depending on value of the "α" angle (b).

The CFD three-dimensional model of the prototype has been developed analogously to the state of the art model of the air manifold. Although all trends observed in case of the 2D analysis have been preserved, significant changes of values have been noted, what was expected due to transformation of the simulation from 2D to a fully 3D case.

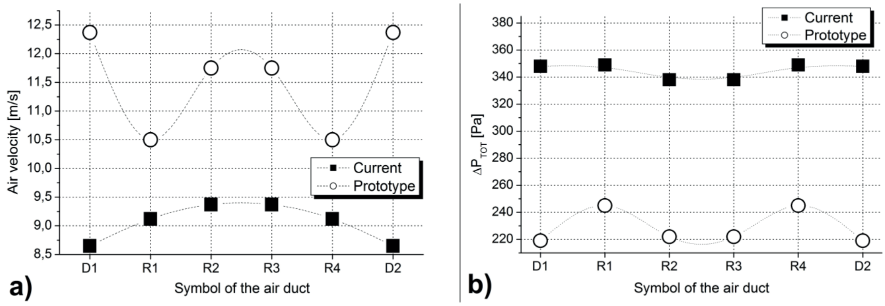

Figure 5. Distribution of selected outlet parameters in case of the basic air manifold and the prototype, inlet air velocity of 12.5 m/s

Generally, in the 2D analysis conducted in ANSYS Fluent, the assumed top and bottom surface of the computational domain is defined by the solver as symmetry planes, which disables the possibility to take the full shape of the device into account. Semi-orthogonal (for the standard manifold) and cylindrical (for the prototype) forms of the manifolds can only be fully projected in 3D. However, the parametric analysis as described in the paper would be relatively complicated and time-consuming for 3D simulations. Thus, due to the general agreement of phenomena in both cases, the applied approach seems reasonable as an introduction to further studies, such as advanced 3D simulations. Figure 5 presents the selected outlet parameters for both designs of the air manifold. Improvement was noted in all important fields under consideration. A significant change was observed especially for the secondary air nozzles, which is crucial from the point of view of preserving appropriate conditions in the secondary combustion chamber of the boiler [Miltner M. 2007]. Chart in the section "b" of the figure corresponds to the difference of the total inlet and corresponding outlet pressures of the air distributor.

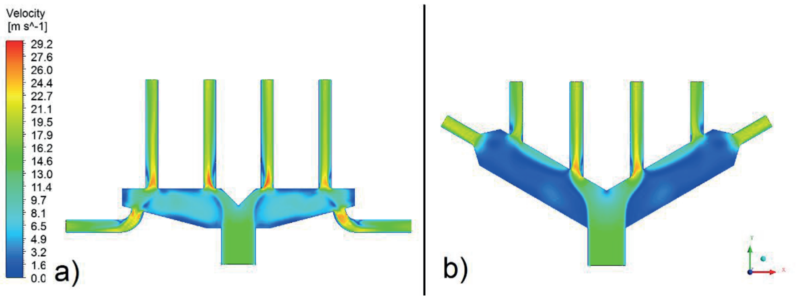

Figure 6. Comparison of the velocity in case of the standard air manifold (a) and the prototype (b): 3D analysis, symmetry plane, inlet velocity of 12.5 m/s.

Based on the comparison of the air velocity distribution (Figure 6) it may be observed that from this point of view the area of the body of the standard manifold is characterized by a more dynamic flow, which results from the complex shape of the device. The air provided by the fan collides with the front wall of the manifold body, because there is no outlet duct located at the direct opposite of the air inlet. The air then flows to the bottom and top wall and again to the rear part of the body. As a consequence, movement of air in the central part of the main duct in the basic air manifold is observed.

4. Summary and conclusions

The paper presents the application of the results of experimental studies performed using the developed stand to validate the CFD model of the state of the art air manifold. Based on the gained knowledge, a new design of the manifold has been proposed. The prototype has been implemented in a CFD environment to develop a 2D model and subsequently to carry out a variant analysis of the impact of changing the bend of the main manifold duct on the output characteristics of the device. In a following stage, all assumptions have been applied in a fully three-dimensional CFD model of the prototype. Important output parameters of the standard and the proposed manifolds, such as air velocity and pressure drop have been taken into account in the study. Improvement of both the considered parameters has been achieved. Simultaneous application of the experimental and numerical methods provides the opportunity to carry out an efficient parametric optimization of elements of the air feeding systems for straw-fired batch boilers. After establishing the terms of cooperation with the investor, the prototype will be manufactured.

This study was carried out within the BioORC project (Faculty of Energy and Fuels, AGH University of Science and Technology, Krakow, Poland). The infrastructure of the Center of Energy, AGH UST in Krakow was used during the research.

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ANSYS Fluent 15 help files

Comparative Analysis of Selected Thermoelectric Generators Operating With Small Scale Heating Appliances

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Abstract

Micro and small scale cogeneration systems are becoming increasingly popular in the residential sector. Among different CHP technologies, thermoelectric generators (TEGs) are an interesting option for houses in which e.g. with boilers and stoves may operate. These appliances may provide self-sufficient operation of the heating devices and – in more advanced cases – generate additional power that may be used by home appliances or sold to the grid.

This paper presents the procedure of testing three types of thermoelectric generators, which may operate with small heating appliances (boilers, stoves or any other heating devices):

- a 45 W_{el} TEG designed for mounting on a flat hot surface which consists of 6 thermoelectric modules, one aluminum plate used for collecting heat and an air fan cooling system;
- a 100 W_{el} TEG designed for mounting on a flat hot surface which consists of 8 thermoelectric modules, one aluminum plate used for collecting heat and a liquid cooling block;
- a 350 W_{el} hot gas-liquid type TEG designed for mounting on chimneys which consists of a hot gas heat collector, 36 thermoelectric modules and a liquid cooling system.

The thermoelectric generators listed above were tested using an experimental set-up with a wood-fired stove, an electronic load, a control and monitoring system with WAGO PFC200 PLC controller and an infrared camera. The operating parameters of the tested TEGs (hot and cold side temperatures, generated power etc.) were monitored using a dedicated application developed in the WAGO e!Cocpit software.

The results of the conducted tests include analysis of the voltage, current and power of the TEGs during the combustion process. The TEGs characteristics in actual operating conditions were compared with the data obtained in laboratory conditions and discussed. Finally, the practical aspects of the operation of thermoelectric generators with stoves were analyzed.

1. Introduction

Thermoelectric generators (TEGs) are devices used to recover low-temperature waste heat for the purposes of power generation. Heat may be recovered from a wide range of heating devices (such as stoves and boilers) and used to provide their self-sufficient operation or to power other domestic appliances. In general, TEG based micro cogeneration systems, should be equipped with a battery charge controller, a battery and an inverter (optionally). The generated power may be consumed by the controller, air throttle servomotor, cooling air fan or other equipment. Excess power may be used e.g. to power a circulation pump in the central heating/hot water system or other home appliances (using the inverter to convert DC to AC power). Unfortunately, such a system is characterized by a limitation in the amount of generated power related to the relatively low conversion efficiency of TE modules (~5%) (Rowe and Bhandari, 1983). On the other hand, the low efficiency problem is not the major issue when a TEG is used for waste heat recovery because of the costless thermal energy input (Riffat and Ma, 2003). From this point of view, a μCHP system with a TEG is generally considered as an additional power source in typical buildings. Such a solution may also be an important part of summer houses or other off-grid installations.

1.1 State of the art

Worldwide literature provides some works regarding the performance analysis of TE modules and the possibility of their application alongside solid-fuel burning stoves.

For example, the electrical performance of commercially available TE modules made of Bi_2Te_3 based materials and installed on a cooking stove's side-wall has been tested by Lertsatitthanakorn. The system had a power output of 2.4 W at temperature difference of approx. 150°C (Lertsatitthanakorn, 2007). Also Nuwayhid et al. have presented a power generating system with TE modules fitted to the side of a domestic woodstove and cooled by natural convection. The maximum matched load power in a steady state was 4.2 W per a single module (Nuwayhid et al., 2005). A complete system with a multifunctional stove allowing for the electric power production by end-users has been studied by Champier et al. In that case, a TE module was efficient enough to produce 9.5 W of electric power, while the maximum power of stable electricity available for the end users was around 7.6 W (Champier et al., 2011). As opposed to air cooling systems, Rinalde et al. studied a forced water cooling system. In this case, an electric heater was used as a heat source and the maximum power obtained was at the level of 10 W. The continuous operation of a pump certainly decreased the output power (Rinalde et al., 2010). Another example of the operation of a TE module cooling by water was tested by Sornek et al. A TE module was mounted on a flue gas channel of a stove-fireplace with accumulation and the maximum obtained power reached 6 W for a temperature difference of 150 K (Sornek et al., 2016). The same TE module was used to analyse different cooling methods. The maximum measured output voltage was 6.1 V while the cold side was cooled by water. The value reached 4.2 V and 2.6 V when forced air and natural air cooling systems were used, respectively (Sornek, 2016).

The possibility of application of a commercially available TEG to a solid-fuel stove has been presented e.g. by Montecucco et al. A thermoelectric generator was used to concurrently charge a lead-acid battery and transfer the heat to water for heating. This system produced an average of 600 W_{th} and 27 W_{el} during a 2 hours long experiment (Montecucco et al., 2015). Mal et al. achieved a power of 5 W, when the thermoelectric generator was integrated with a biomass cookstove. The generated electricity was stored in a Li-ion battery and further used for running a 12 V DC fan, lighting a LED light, and charging a mobile phone (Mal et al., 2015). Other tests were described by Liu et al., where thermoelectric modules operated at different conditions (including varying inlet temperature and temperature differences between hot and cold sides). The power generator comprising of 96 TEG modules had an installed power of 500 W at a temperature difference of around 200 K, and an output power of about 160 W at a temperature difference of 80 K (Liu et al., 2014). The performance analysis of the hybrid thermoelectric generator (Bi_2Te_3-PbTe) was presented by Angeline et al.. In that work, it was concluded, that the use of a hybrid TEG corresponded to approximately 53.4%, 21.7% and 39.6% average improvement in power, voltage and current production respectively, as compared to that of an ordinary Bismuth-Telluride (Bi_2Te_3) module (Angeline et al., 2017).

The analysis of the available literature sources confirms the validity of further research in the area of using thermoelectric generators in μCHP systems. The investigation presented further herein includes practical aspects of the use of air cooling type and water cooling type TEGs designed for mounting on chimneys and flat hot surfaces.

2. Materials and methods

The experiments were carried out using a dedicated test rig equipped with a heat source, thermoelectric generators, infrared camera and a measuring, controlling and visualizing system.

- **Heat source.** A steel plate stove devoted to burning seasonal hardwood (with humidity up to 20%) and brown coal briquettes was used as the heat source. The heating capacity of the unit is in the range from 8 to 16 kW.
- **Thermoelectric generators**. Three types of TEGs were taken into consideration:
  TEG No. 1: a 45 W_{el} TEG designed for mounting on a flat hot surface which consists of 6 thermoelectric modules, one aluminum plate used for collecting heat and an air fan cooling system,

  TEG No. 2: a 100 W_{el} TEG designed for mounting on a flat hot surface which consists of 8 thermoelectric modules, one aluminum plate used for collecting heat and a liquid cooling block,

  TEG No. 3: a 350 W_{el} hot gas-liquid type TEG dedicated to use in automobiles which consists of a hot gas heat collector, 36 thermoelectric modules and a liquid cooling system.
- **Measurement, control and visualization system**. The system was based on the WAGO PFC200 Controller. The system consists of a thermocouple and resistance sensors placed inside the furnace and chimney (t_{in1}, t_{in2}), on the rear wall (t_{out1}, t_{out2}, t_{out3}), on the water inlet and outlet to the TEG (t_{wat1}, t_{wat2}) and on the air inlet to the TEG (t_{air}). The regulation of the air flowing into the furnace was possible by means of a throttle. The monitoring and process (measurement) data acquisition system was developed in the WAGO e!Cockpit software.
- **Infrared camera.** The NEC Thermo Tracer H2640 infrared camera was used to analyze the temperature distribution on the rear wall of the stove. This camera featured a 640 x 480 image resolution and a temperature range from 0 to 500°C.

The general scheme of experimental rig is shown in Fig. 1.

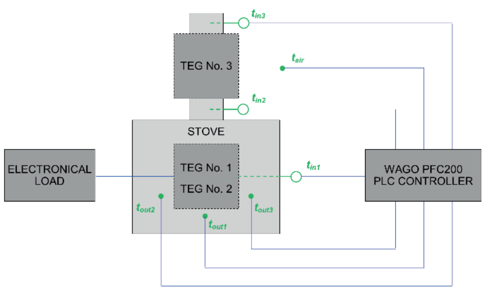

Fig. 1: The general scheme of experimental rig.

3. Results and discussion

The conducted study has been divided into two parts: (i) the thermographic analysis of the stove's rear surface temperature for the case of flat mounting of TEGs, (ii) the operating characteristics of all considered TEGs.

3.1 The thermographic analysis of the operation of the stove and flat mounted TEGs

Due to structural parameters of the tested stove, the thermoelectric generators may be placed on the rear wall and the chimney. Temperature distribution on the rear surface was analyzed using infrared thermal camera during the combustion of 8 kg of dry beech wood. An area could have been noted (indicated by the box in Fig. 2a), where the temperature level was sufficient to power flat mounted TEGs. The average temperature in this area was 390°C, while the minimal observed value was about 230°C and the maximal temperature exceeded 500°C. Naturally, such a high temperature is not achieved during the entire combustion process. This time is dependent e.g. on the amount of the fuel load determining the length of the combustion process, and by the method of control of the stove's operation.

As it has been shown in Fig. 2b, TEG No. 1 was located centrally on the rear wall (in the area where temperature reaches the highest level). A certain difference in the temperature distribution in comparison to the previous situation may be noted – Fig. 2a. As a result of heat dissipation by the TEG's cooling system, the area near the TEG (indicated by the arrows) is heated to a lower temperature as compared to the remaining part.

Due it's excessively large dimensions, TEG No. 2, was vertically mounted on the left side of stove's rear wall (see Fig. 2c). Such a location resulted in the fact that about 30% of the TEG No. 2 hot surface was in the area where temperature was lower than 220°C (indicated by arrows). As a result, the TEG's surface was not heated uniformly.

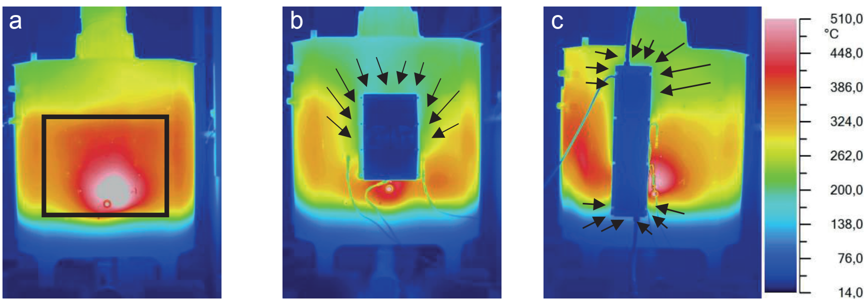

Figure 2: Thermographic analysis of the temperature distribution of the stove's rear surface: (a) without generators, (b) with TEG No. 1 mounted, (c) with TEG No. 2 mounted

3.2 The operating characteristics of the studied TEGs

The operational parameters of the TEGs – the voltage, current and the generated power – changed along the variations in the temperature of the hot and cold sides of the thermoelectric generators. During the tests, the temperature of the cold side was constant over time (23°C both for cooling water and air), while temperature of the hot side resulted from the actual combustion process phase. The I-V characteristic was performed for the time in which hot side temperature was near the optimal temperature according to manufacturer's requirements. As it may be noted in Fig. 3, I-V characteristics of the TEG No. 1 and TEG No. 2 are almost similar (TEG No. 2 reached a bit higher voltage). On the other hand, the I-V characteristic of the TEG No. 3 significantly differs from the above – the obtained open circuit voltage was more than 2 times lower as compared to the other TEGs.

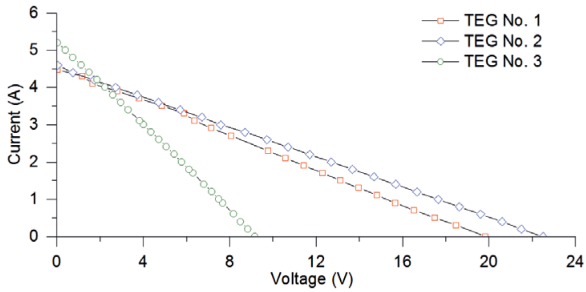

Figure 3: I-V characteristics of the thermoelectric generators.

As a result of the current and voltage variations, the power generated by TEGs was also different and it was significantly lower than their nominal power. The TEG No. 1 operated at 22.5 W at the maximum power point (50 % of its nominal power), while the TEG No. 2 operated at 25.8 W (26 %) and the TEG No. 3 – at 12,3 W (3.5 %). Such a high difference in case of the TEG No. 3 resulted from the insufficient cross section of the smoke channel (6 cm compared to the nominal 20 cm). As a result, the flow of the flue gas was significantly lowered, which caused a problem with fuel burning (long combustion process alongside small heat generation) and reduced heat flux to the hot side of the TEG No. 3. Similarly, in case of the TEG No. 1 and the TEG No. 2. The surface temperature that was not uniform reduced the heat flux to the hot side of the TEGs and the obtained power (see Fig. 4).

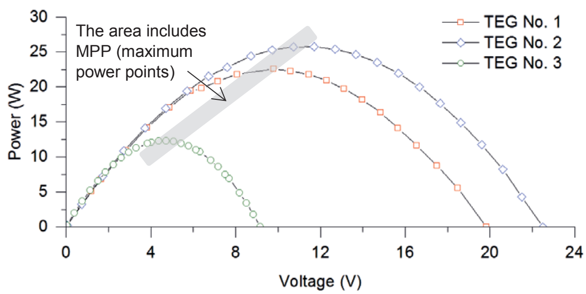

Figure 4: P-V characteristic of the considered thermoelectric generators

3.3 The comparison of the obtained results with operation in laboratory conditions

TEG No. 1 served for the comparison of the operating parameters in actual and laboratory conditions (see Fig. 5). It is visible that the power obtained in actual conditions has a more flat characteristic and in case of 350°C, it was possible to obtain only 20 W as compared to the 30 W provided by the manufacturer.

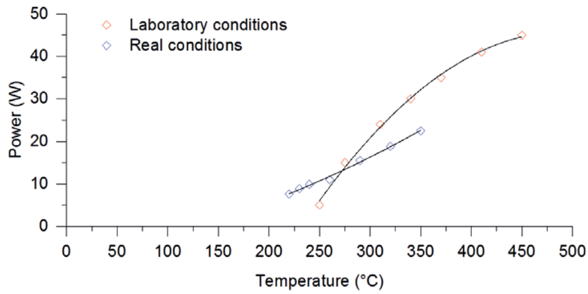

Figure 5: The comparison of TEG No. 1 operating parameters in actual and laboratory conditions.

4. Conclusions

Thermoelectric generators are currently considered as a promising energy source operating alongside home heating devices. One of the purposes of such a cogeneration system is to provide a self-sufficient operation. It is extremely important in locations where power grid is not available or frequent power grid failures are encountered. According to the authors' experience, a part of stove manufacturers are interested in equipping their devices with TEGs. However, although it seems to be a relatively simple task, a problem with proper selection and complicated use of thermoelectric generators arises. Here, the operating and the maximum hot side temperatures as well as the required cold side temperature are the most significant factors. The proper mounting allowing to obtain good contact and sufficiently high heat flux is also essential. The thermoelectric generators available on the market are not usually designed to cooperate with home heating devices. The result is the fact that TEGs' nominal power parameters are impossible to reach in such conditions. The tests of three market available thermoelectric generators that have been presented in the paper, exhibit that the following parameters are crucial: the size of the hot sides, the surface smoothness, the required heat flux and sufficient temperatures. As it has been shown, it was possible to reach a power corresponding to 3.5 % of the nominal power for TEG No. 3, 26 % for TEG No. 2 and 50 % for TEG No. 1. These results may be genuinely useful for the heating devices manufacturers - the two possible approaches are:

- introduce necessary modifications to the heating devices (appropriate flat area with sufficient heat flux, additional fan for flue gas, etc.)
- development of a dedicated structure of the TEGs.

These two methods would differ in terms of costs, final product price and necessary fitting of producing lines.

Acknowledgements

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GIS modeling on Urban Ecological Security Patterns for the Sponge City

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Abstract

The constructor of sponge cities in China advocates the general principle of ecological priority and low-impact development, which requires a comprehensive analysis of the ecological factors related to urban rainwater resource utilization and clarification of the urban ecological security pattern. Combining with the first-hand planning of the sponge city construction in Zhengzhou, this paper analyzes the key ecological environmental factors associated with the accumulation, penetration and purification of rainwater in urban areas, based on the investigation and analysis about the distribution of the factors of water ecological factors, water project, orographic factors and contingency sponge body. These factors include wetland, vegetation, farmland, water source protection zones, large-scale project, natural scenic region, elevation, slope, river corridor based on DEM and low-lying areas based on DEM. The aquatic ecological sensitivity of Zhengzhou was analyzed using an analytic hierarchy process and space superposition method. The paper integrates the ecological security pattern of sponge cities and explores how to maximize the functions of the original ecosystems in the city and enhance the ecological function of "infiltration, stagnation, accumulation, purification, usage and transpiration" and proposes a targeted strategy for sponge city planning and construction.

1. Introduction

Urbanization has brought the rapid expansion of construction land. A large number of natural landscape, such as the cultivated land, woodland, wetlands, was replaced by impervious surface. As a result, the capacity of flood discharge and flood storage of the surface was significantly reduced, and the original process of natural water cycle such as rainfall interception, infiltration, evaporation was damaged, leading to a series of urban flood management issues: frequent flooding, deteriorating water environment and serious water shortages (Xu, 2016; Ahiablame, 2012). The water crisis brought about by these water problems is a systematic and integrated problem, and it need more comprehensive solution (Yu, 2015).

Restrictions for a single structural flood-control ability have been more and more recognized around the world, and it has become an important trend of flood control and disaster reduction to rationally plan the regional water network such as rivers and lakes, thus to fully play the hydrological regulation function of natural ecosystem including infiltration, discharge, storage and stagnation (Peng et al, 2016). The United States is one of the earliest countries to study the rain flood regulation, and imposed the "flood detention on the spot" for all new development zones from the 1980s, which requested that the rainwater runoff of the alteration or construction project should not exceed the pre-development level (Dietz, 2007). Best management practice (BMP) system, low impact development (LID) system and green infrastructure (GI) are all control the runoff at the source by natural hydrological control such as penetration, filtration, storage, volatilization and retention, with the help of landscape elements in the site, attempting to minimize the cost of storm water management by taking a “design with nature” approach (Walmsley, 2006). Then the United Kingdom developed the “sustainable urban drainage systems (SUDS)” based on the LID system in the late 1980s (Spillett, 2005). In the 1990s, Australia and Canada established the water sensitive urban design (WSUD) system with the whole urban water cycle as the core (Wong, 2006). The utilization of urban rainwater in China started later. Until April 2012, the concept of "sponge city" was first proposed in China. Unlike the Australian population study scholar Phuket applied “sponge” to describe the adsorption of city's population, the term ‘sponge city’ in China describes cities that are able to adapt flexibly, like sponges, to changes in the environment, such that they absorb, store, permeate and purify rainwater, and are able to make use of the stored water when needed. The approach aims to improve the function of urban ecosystem and reduce the occurrence of urban flood. "Sponge" is the water ecological infrastructure with landscape as the carrier. The proposal of "Sponge city" is based on China's hydrological features, and innovated and developed on the basis of the theory of international rainfall and flood utilization. From then on, Chinese scholars pay much attention to the study of spongy city. In November 2014, the Ministry of housing and urban rural development issued the technical guidelines for the construction of sponge cities - Construction of a low impact rainwater system (for Trial Implementation), which formally put forward the construction of sponge cities, and set up 16 pilot cities of sponge city construction. China began to carry out multidimensional exploration of the related construction of sponge city from the national and urban scale, and the research on the theory and practice of sponge city was furious. With the deepening of theoretical research, more and more scholars have begun to explore the practice of sponge city. However, most of those cities focus on the technical detail part of district, block, community, and pavement etc., lack of comprehensive consideration on whole urban system, let alone macro system level. Meantime, many literatures have gradually focused on how to protect the natural wetland and restore the damaged water system. Those also believe that sponge city needs to focus on the spatial pattern of water system in the region or watershed at the large scale, that is, the analysis of water security pattern.

The theory of ESP holds that some potential spatial patterns in the landscape are made up of certain key locations and spaces and of very important significance in the sustaining capacity of the environment. To build the EPS, the ecological function can be ensured to embody, and with the least possible land use, the best pattern, the most effective way to maintain the landscape of various ecological processes of health and safety. The above concepts and method are illustrated with a case study, Zhengzhou city, Henan, China. A GIS model was designed to build the Ecological Security Pattern (ESP) for sponge city.

2. Introduction

2.1 Study area

Zhengzhou is the capital of Henan Province, one of China’s eight ancient capitals. The city is located between east longitude 112°42' – 114°14' and north latitude 34°16' – 34°58' and has the jurisdiction over 6 municipal districts, 5 county-level cities and 1 county. Zhengzhou is located in the southern part of the North China Plain and crosses China's second and third geomorphic steps. The southwestern Songshan belongs to the second-level geomorphic front edge, while the eastern plains belong to the third level of landforms, between the mountains and plains, with low hilly terrain. The general trend of the topography is that the southwest is higher than the northeast.

As a result of the complex terrain, the distribution of rainfall in Zhengzhou is uneven, and generally, the trend exhibits a gradual decrease from south to north. Zhengzhou has a large population and very scarce water resources. The annual per capita water resources of the city are 179 m3, which is approximately 1/2 of the per capita water resources of Henan Province and 1/10 that of China. According to the internationally recognized standard of severe water shortage per capita, 500 m3, Zhengzhou is a serious water shortage area. In addition, the proportion of impermeable surface increases due to rapid urbanization, and the corresponding drainage facilities are not complete; as a result, when Zhengzhou experiences heavy rains, waterlogging becomes very serious and many security problems arise.

The construction of a sponge city is an effective way to solve the problems of water shortage and waterlogging in Zhengzhou. In June, 2016, according to the provincial government document "views on promoting the implementation of the sponge city", Zhengzhou outlined the planning area of sponge city construction. The planning area includes all areas of Zhongyuan District, Huiji District and Jinshui District and some parts of Erqi District, Guancheng Hui District, Shangjie District, Xingyang City, Xinzheng City and Zhongmu County (Figure 1). The study take the entire city of Zhengzhou as the research area, explores the means of constructing an ecological security pattern for a sponge city, and provides sponge planning area construction guidance according to the security pattern.

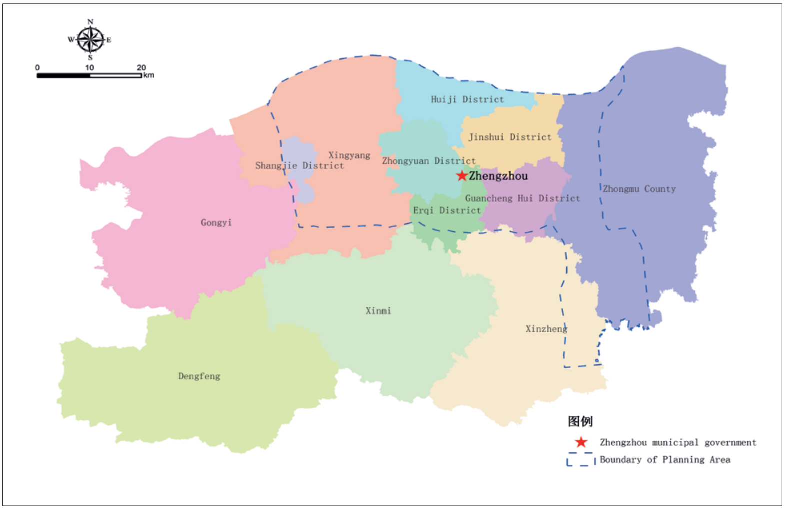


Figure 1. Zhengzhou administrative boundary and the Planning Area of Sponge City

2.2 Research area

Research data of sponge city is primarily made up of spatial and attribute data. Spatial data comprises data on baseline spatial information, distinctive natural features, infrastructure spatial positioning (roads, pipe networks, etc.), boundaries, controls, rivers and drainage systems, current land use and planning, urban planning, and urban construction administration. The coordinate system of GIS data was the Beijing_1954_3_Degree_GK_Zone_38 Coordinate System, while the other datasets referred to the WGS1984 Web Mercator Coordinate System.

2.3 Methodology

2.3.1 Theory analysis about Ecological Security Pattern

The theory of “Sponge City” is formed in response to China’s city water issues. Construction of ecological security patterns is an important approach to protecting urban ecological security and achieving urban sustainable development, which is one of key topics in the research of landscape ecology (Chen et al., 2017). A new approach is necessary to carry out an in-depth study that will be helpful for further enhancing the process of urbanization and protecting natural ecosystems in China. Part of Ecological Security Pattern, such as water resource security, water environmental security, flood evasion security, and water ecological security need to be compare and analyze.

The identification of ecological sources and the construction of spatial resistance surface have been the key technique in the study of ecological security pattern. Based on GIS, ecological sources were identified from the aspects of ecosystem services' importance, ecological sensitivity, and landscape connectivity. The framework of importance- sensitivity connectivity can provide a new method for the construction of regional ecological security patterns, and the study results can provide related planning with effective spatial guidance.

2.3.2 Modes and approaches to build the Security Pattern

With AHP, the Index system on the Security Pattern of sponge city was built. Its flow chart shown in figure 2.

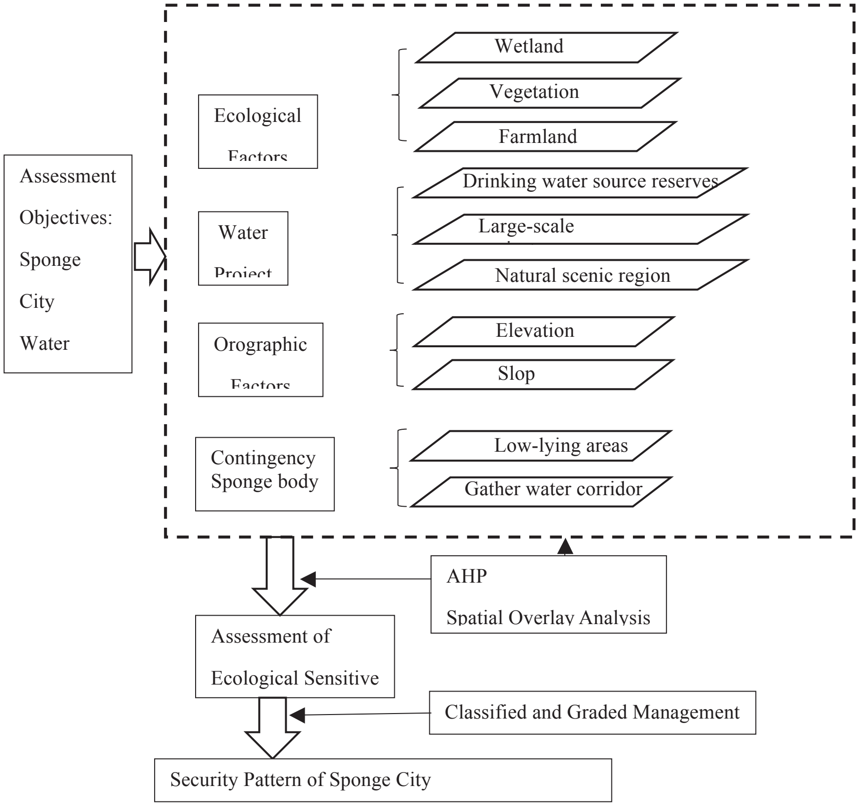


Figure 2. Flow chart of Index system on the Security Pattern of sponge city

2.3.3 Establishing index system using AHP

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. The AHP helps decision makers find one that best suits their goal and their understanding of the problem. This model contains the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternative. There are four Alternatives for reaching the Goal of sponge city water security, and four Criteria, such as current ecological factors, water project factors, orographic factors and Contingency sponge body, to be used in deciding among them.

2.3.4 Computing Weight

With many questionnaire from expert and Matlab R2016a software, each weight was shown below table 1.

Table 1. Index system and weight based on AHP

Goal	Criteria	Alternative (i)
Sponge City Water Security	Ecological Factors (0.2746)	Wetland (0.5695)
		Vegetation-covered area (0.3331)
		Farmland (0.0974)
	Water project (0.5753)	Drinking water source reserves (0.3196)
		Large-scale project (0.5584)
		Natural scenic region (0.1220)
	Orographic Factors (0.0911)	Elevation (0.4000)
		Slop (0.6000)
	Contingency Sponge Body (0.0589)	Low-lying areas generated from DEM (0.5000)
		Gather water corridor generated from DEM (0.5000)

For consistency check of Criteria level, their CR are 0.0212<0.1, CR = 0.0158<0.1.

2.3.4 Comprehensive evaluation based on GIS

Modelling ecological sensitivity

The comprehensive analysis of ecological sensitivity mainly used the GIS spatial superposition analysis technique to synthesize the spatial layers of every factor (Dong et al, 2016). The software platform was ArcGIS 10.2, and the specific formula is as follows:

$$ES = \sum_{i=1}^{10} W_i F_i$$

In the formula, ES is the ecological sensitivity composite index, F_i is the ecological sensitivity grade value of factor i, and W_i is the ecological sensitivity weight of factor i.

Identifying ecological sources

To develop the sponge's city, ecological sources were play important role, because those patches were very sensitive for ecological process, biodiversity protection etc.

Exploring the ecological corridor through MCR model

Using minimum cumulative resistance model, ecological corridors were identified. Three parameter, such as ecological resources, distance and feature of landscape boundary, the formula is below.

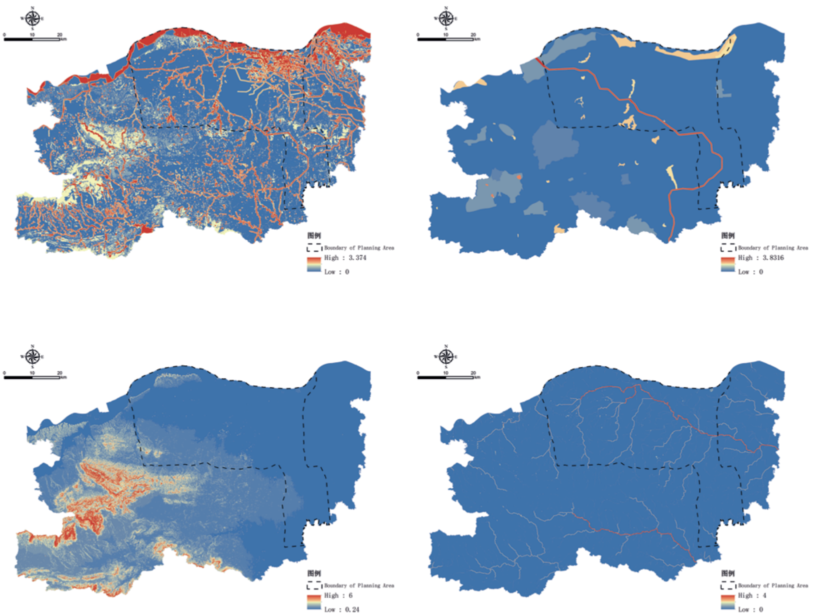
$$\mathrm{MCR} = f_{min} \sum_{j=n}^{i=m} D_{ij} \times R_i$$

In the formula, MCR is value of minimum cumulative resistance; Dij is distance form patch j to i, Ri is resistance coefficient of I, f is positive correlation relationship.

3. Results

3.1 Distribution pattern of the key security factors

(a) Distribution pattern of water ecological factors; (b) Distribution pattern of water projects, (c) Distribution pattern of orographic factors; (d) Distribution pattern of contingency sponge body.



3.2 Characteristic of Ecological Sensitive Areas

In the case of ecological sensitivity classification, national natural scenic region covered with vegetation were considered to ensure the highest ecological sensitivity, and the area without the important ecological sensitive factor was the lowest in sensitivity. Therefore, the threshold of the highest sensitive area was 0.8996, while the threshold of the lowest sensitive area was 0.1206. The other three areas were divided according to the equal break method. The use of this partitioning method is helpful in reflecting the spatial uniformity of sponge in different areas of the city. The specific classification is shown in Table 3.

Table 3 Classification of the Ecological Sensitive Areas in Zhengzhou

Ranks of Ecological Sensitive Areas	Ecological Sensitive Index ES
The Highest Sensitive Area	≥0.8996
The Higher Sensitive Area	0.6399-0.8996
The Moderate Sensitive Area	0.3802-0.6399
The Lower Sensitive Area	0.1206-0.3802
The Lowest Sensitive Area	<0.1206

3.3 Ecological Security Patterns for the Sponge Zhengzhou

Based on the comprehensive analysis of aquatic ecological sensitivity, the comprehensive ecological sensitive zoning map of sponge city construction in Zhengzhou was obtained (Figure 2).

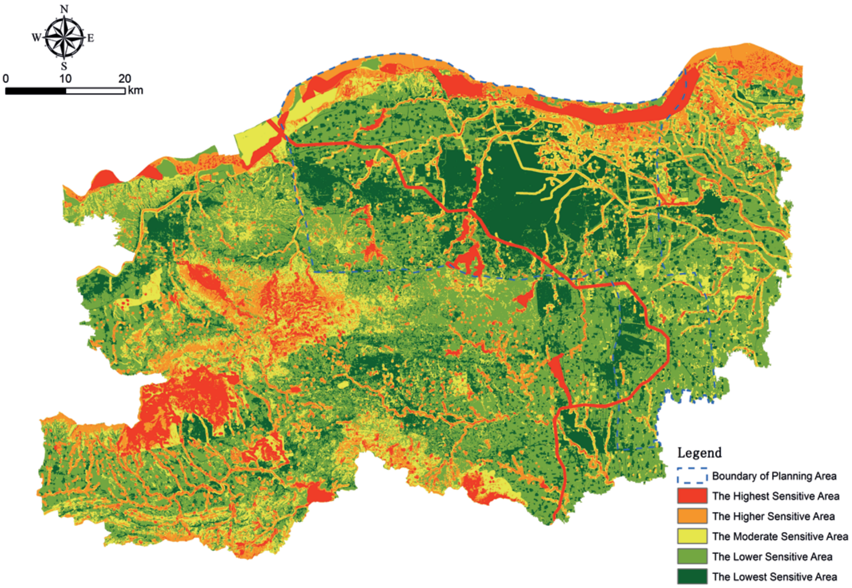


Figure 2 Comprehensive Ecological Sensitive Zoning in Zhengzhou

The highest ecological sensitive areas in Zhengzhou mainly include the northern wetlands along the Yellow River, the South-to-North Water Diversion Project that runs through the urban area and the riparian protection area, the Songshan-based mountainous areas in the southwest, the water source protection zones around the urban area, and several natural and cultural scenic spots covered with vegetation. These highest sensitive areas should be especially protected in the sponge city master plan. There are also several major river systems in the planning area of the sponge city. These water systems are also higher sensitive areas and have important functions, such as water conservation, urban and rural water supply, flood control and drainage. These higher sensitive areas are important areas that must be protected during the planning and construction of the sponge city and are the most operable targets for improving the ecological security pattern. In addition, the higher sensitive areas are present in some natural and cultural scenic spots, which should also be included in the ecological security pattern of the main body.

The rivers are basically around the sensitive area and act as a buffer to the sponge protection. In addition, the sensitive areas are distributed in the mountainous and hilly ecotone vegetation areas. These areas belong to the river source areas, where water conservation and soil conservation functions are more prominent. The relatively low sensitive areas are mainly distributed in the peripheral areas of the built-up area, which is rich in agricultural resources. It should be paid more attention to the protection of high-quality farmland in the process of sponge city construction.

From the perspective of the city's domain scale, the Zhengzhou sponge city planning area basically lies in low sensitive areas, with low vegetation coverage and the potential for urban ecological security functions. According to an analysis of the direction and function of the future urban master plan of Zhengzhou, different ecological sensitive areas are effectively zoned, and the corresponding planning is proposed, as shown in Table 4.

Table 4 Analysis of the Area of Different Types of Ecological Sensitive Area and Planning strategy

Ranks of Ecological Sensitive Areas	Area (km^2)	Proportion	Planning strategy
The Highest Sensitive Area	697.97	9.22%	To list the Yellow River wetland area, the central line of the South-to-North Water Diversion Project and drinking water source protection areas as important protection areas, and increase the intensity of forest ecological resources protection and improve water conservation function, prevention and control of water and soil erosion and other issues.
The Higher Sensitive Area	1135.33	15.00 %	To strengthen the protection of the integrity of the system, reduce the river diversion and closure, and strengthen the connectivity of rivers and other sponges.
The Moderate Sensitive Area	1363.30	18.02%	To improve the vegetation coverage rate of the river buffer and protect the ecological function of the river.
The Lower Sensitive Area	2968.31	39.21%	To pay attention to the protection of basic farmland, and reduce the occupation of farmland.
The Lowest Sensitive Area	1402.00	18.53%	To reduce the proportion of the hardening of the ground, and increase the permeability of the pavement, sink type green space, green roof and other facilities and devices to increase rain infiltration.

3.3.2.3 Ecological security pattern analysis

According to the comprehensive analysis ecological sensitivity and the characteristics of ecological factors related to the construction of the sponge city, this paper puts forward the ecological security pattern for sponge city construction in Zhengzhou from the perspective of the integrity of the urban ecosystem. The pattern includes the ecological protection zone, ecological conservation area, sponge city construction area, sponge buffer area, and sponge network (Figure 3). Different ecological security pattern components have different characteristics, which should be treated differently in the construction of the sponge city.

4. Discussion

4.1 Key ecological protection area to build sponge city

The main part of the ecological security pattern of Zhengzhou is the Yellow River riparian wetland ecological zone, which located to the north of Zhengzhou. The second important is the central line of the South-to-North Water Diversion Project ecological zone, along the west of Zhengzhou. The water source protection areas should be strictly delineated along the two key ecological protection zones, prohibiting construction and development in surrounding water sources, focusing on the protection of the ecological environment in the Yellow River riparian wetland, repairing the conservation of water resources and water supply ecological function of the Yellow River, improving flood control capacity, and enhancing the function of water storage and drainage of ecological protection zone. Effectively enhancing the protection of the urban ecological system while maintaining its role as an important ventilation corridor in the city effectively alleviates the hazards of Heat island and Rain Island.

4.2 Link the sponge body in whole city

The inner city river not only provides water resources for river landscape, but also is the urban water supply and drainage discharge, among other functions. An aquatic ecosystem restoration project should be undertaken both to control and govern water pollution and to recover the connectivity of rivers. The existing single river, lake and other sponge nodes with low water availability and fragile ecological integrity are incorporated into the river system of sponge city construction to form a water system network with multiple water source protections and with hydrodynamic characteristics. Sponge nodes and river corridors constitute a special intestiniform sponge network, help maximize the water storage and drainage capacity of sponges, and improve the urban aquatic ecosystem service function.

4.3 Cultivating conservation area in suburban

In the urban ecological security pattern, ecological conservation areas serve the function of water conservation and forest conservation. This area is rich in forest resources and biodiversity, and it is also the source of the river, which has an important water conservation function. Effective conservation of the area is an important maintaining water resources in Zhengzhou.

For the ecological conservation area, the function of soil and water conservation in this area should be further promoted to supply groundwater in the planning area. A natural forest protection project should be implemented in the mountain areas and in Forest Park to establish the ecological forest system whose main function is soil and water conservation. It is important to actively clean up the small watershed of the mountain and reduce pollutant load. The management of small and medium rivers should be improved, embankments and rainwater cisterns should be constructed, and the safety coefficient of the river upstream of the planning area should be improved. The development and construction of water source protection zones should be prohibited to ensure the function of water conservation and supply in the ecological conservation area.

4.4 To promote urban flood resilience

The ecological buffer of the ecological security pattern provides a transitional zone between the ecological conservation area and the urban construction area, which plays a protective role for the important sponges to prevent the degradation of ecological conservation areas because of the expansion of the city.

In the construction of the sponge city, the government should strengthen the ecological protection of the ecological buffer and build a buffer system of ecological forests to prevent the disorderly occupation of the ecological corridor resulting from city construction, to better maintain the ecological service function of the ecological buffer, and to curb the disorderly spread of built-up areas as much as possible. To interconnect the urban ecological isolation corridor with the main traffic road and urban green corridor, forming an ecological landscape pattern with the combination of network and surface in the planning focus area.

4.5 Focus on the planning of sponge construction area

As the sponge construction area, due to the lack of underlying surface change and urban green space, the low sensitive built-up area is facing a series of ecological problems, including urban waterlogging, decline of groundwater level and groundwater pollution. In the process of developing and constructing the sponge construction area, it is important to devise a relatively safe planning strategy of the sponge city.

In the development and construction of the sponge construction area, attention should be paid to the development of a low-impact system of rainfall management. In the city infrastructure construction, it is important to break from the traditional concept of rainfall management with drainage and high-intensity development and instead make full use of city green space and aquatic systems to obtain "sponge" effects, such as accumulation, infiltration, purification, and release. Using infiltration, detention, storage, purification, use, drainage and other ecological technologies helps build an urban low-impact development system of rainfall management based on construction, roads and green spaces. In the case of rain, rainwater is absorbed through the construction of “absorption, storage, infiltration, purification” systems, which are used to replenish groundwater during drought and to regulate water circulation. Through the construction of a sponge city, the damage of the original city aquatic ecological environment can be minimized, realizing the effective use of rainwater resources and thus greatly alleviating the urban waterlogging and water shortage.

5. Conclusion

In the process of sponge city construction, we should first deeply analyze the background conditions of the urban ecosystem and plan the overall ecological security pattern of the city. Then, we should analyze factors related to aquatic ecological sensitivity one by one and give full play to the advantage of the city and its surrounding natural ecological elements of internal accumulation, natural infiltration, and natural purification. The large natural sponges such as mountains, wetlands and large green areas should be given priority to the protection planning. The main river systems and green belts and other ecological corridors should be effectively connected, and sponge areas such as city parks should further play node advantage. According to local conditions, to carry out construction of the sponge city, we should respect nature, comply with nature, and protect nature to ensure the urban ecological security and sustainable development.

Taking a typical city of the Yellow River Basin as an example, this paper has carried out a comprehensive analysis of multi-factors aquatic ecological sensitivity for the construction of a sponge city and constructed a targeted urban ecological security pattern. This concept is a systematic and scientific way to guide the construction of a sponge city and can also be used in reference to other cities in China. However, due to a lack of data, some analysis of the factors regarding the sponges is not sufficient; missing factors include the spatial distribution of rainfall, groundwater depression distribution, and others. Due to the resolution of the spatial data, the urban green space analysis is not detailed enough and should be improved.

Acknowledgment

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Segmentation of urban energy-pollution using Roegenian partial processes with borders

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Abstract

The energy use, oxygen production and pollution (EO2P) have few quantitative metrics simultaneously for EU urban or rural areas. The division of cities into partial Roegenian processes (pRP) with spatial-temporal boundaries offers a solution for decision making based on EO2P metrics. The territorial reference units (TRUs) is a pRP. The C(O2) vehicle flow sequestration is considered a health indicator, as a basic condition for wellbeing in every small living area (pRP), not in a Whole City. Our research identifies spatial-temporal boundaries and flows of EO2P for public RTUs (pRTUs) in Timisoara. The street surface, including the sidewalk and parks, is considered inside the pUTR borders. The O2 production is the first partial process of pRTU1 process. The energy-pollution of cars is the second pRTU2 process. The equilibrium point for living is C(O2) neutral for every RTU. Our research goal is the modeling of border-input frontier flows for several pRTUs for EO2P in Timisoara to achieve C sequestration. The goal of a concrete human being located in a city is life enjoyment and wellbeing within every urban RTU. The sequestration of C is considered internal flow for Whole pRTU. The flow measurement for pRP sustains decision making to avoid the heat island and to maintain the wellbeing-health of people. The measurement of EO2P reveals different figures for each RTU. In Timisoara during the summer in the three main pRTUs, the car flows between 2-5 times greater for C emission compared to C sequestration by tree. The city hall area records a complete C sequestration (and also neutral CO2).

1. Introduction

The large urban energy consumption and high pollution in the EU is usually justified with population density (EEA, 2015, Yeo, 2013) for a unified framework (Bettencourt, 2010). The few integrated macro-measurements on EU rural-urban energy consumption (IEA, 2008) for direct and indirect consumption are not based on detailed observations, which to be then aggregated. The EU researches was developed using these figures (EEA, 2009; EEA, 2010). Some researchers have modeling the urban and rural households (HH) energy direct HH consumption for each EU country (Dogaru, 2016). Detailed measurements up to the TRU, as micro-zone, are waiting to serve further for decision-making for urban development[1]. The IEA trend estimations of EU energy consumption for the period 2005-2015 on total urban consumption have been denied by Eurostat figures. The solution is to check the estimation (Stern, 2016). The absence of detailed measurements for cities has generated the comparison of urban energy efficiency with other non-urban, regional, national, European. In the absence of accurate figures (and consequently of comparison) of the level of another process more efficient, it is difficult to set targets such as 20-20-20 (CofEC, 2008) for micro-zones. It is the enlightening example to split parts of the 20-20-20 target for each city and then micro-zones.

[1] http://www.primariatm.ro/index.php?meniuId=2&viewCat=3257

In parallel with the study of urban energy consumption, the pollution was observed (Hargreaves, 2016). It has been studied on the basis of operational self-assumed tasks at European level (Covenant of Mayors) separately for transport (streets) and separately for dwellings (PMT, 2014). These estimates ought to be repeated on a recent basis according to these tasks. The tasks are not assigned to the micro-zones.

In urban transport, the vehicle flow measurements for main and connecting streets were made (to see footnote 1, map T03 with vehicle flows). They were not aggregated for entire city like Whole (Georgescu-Roegen, 1971). For urban areas sometimes the average vehicle speed was calculated to estimate urban traffic. Individual transport is the largest consumption in a city. For EU countries, only total (urban and rural) total consumption for individual transport (CP0732, Eurostat site) is known. Other studies note consumption in relation to vehicle types, fuel characteristics. In some cases, transport pollution is estimated in summary terms according to some coefficients (PMT, 2014).

In some cities, detailed calculations were made for the production of O2 in public spaces (Ciupa, 2005). This public space overlaps with that of pedestrians and vehicle, having established spatial and temporal borders. The segmental spatial knowledge of energy consumption effects in non-public public spaces, O2 production and pollution (EO2P) appears necessary. An operational solution is the use of the Roegenian flux-funds model. In the Roegenian model, individuals act in well-defined spatial and temporal boundaries (Georgescu-Roegen, 1971). EU energy consumption is concentrated in buildings (individual and public) and transport (Mathew, 2015). Under these circumstances, for the EO2P it is necessary to classify the cities initially in two spatial areas: the public areas streets and sidewalks related to transport and in the private areas - buildings and land areas. The economic and social processes in urban and rural areas are analyzed in urban research for TRU. In Timisoara there are about 200 such micro-zones. In other studies, the city was divided for green inventory in micro-zones, for an area of 2992 ha and for 350 km of street length (from 650 km; Ciupa, 2005). For systemic analysis these main urban processes can be divided in 2 pRP: for pTRU and for private processes (prTRU) including buildings and adjacent land area (non-street). The analysis at this micro level can thus justify and to validate macro surveys of each city according to macro measurements (IEA, 2008).

The standard classification (SNA) can help to identify the activity of firms and individuals inside of spatial and temporal borders (Georgescu-Roegen, 1971). Data can by also to be compared with other data. In the absence of rigorous spatial classifications, the observed processes can overlap or remain gaps between data noticed. [2] The measurement solutions occur by observing micro-disaggregated (detailed) levels at the street level, nano-zones (Ciupa, 2005). The division of urban

[2] In the absence of a unitary spatial classification of pRP (to see footnote 1), none of the 4 basic principles of science can be strictly supported. The urban-rural classification is overlapped and assumed similar without explanation in the recent Heating & Cooling 2016 Strategy with the metropolitan and non-metropolitan regions (EC,2016a; EC, 2016b). Essentially, the passing through gateway to science, classification, is not validated in this case.

reality into partial Roegenian processes is a fine operation, being dependent on the established purpose. A justification for the difficulty of integrated analysis is generated by setting different spatial-temporal boundaries for different purposes for the same partial process. It is the case of micro-zone, urban RTU. Comparison is not possible in this case without the harmonization of data integration. By using urban nano-zones (Ciupa, 2005), with some data processing, aggregations can be made on any official or proposed (ad-hoc) RTU as micro-zone. The solution provided by the Roegenian model is an external addition of nano-zones. For example, avoiding double counting of the levels of some features - flows, funds, agents - is need the observation of internal flows of partial processes (Georgescu-Roegen, 1971).

To serve macro public decisions, the measurement of energy consumption and pollution can be made on the pRP from the economic, social and natural reality. SNA accounts are based on external aggregations of the economic processes of companies (localities) at a detailed level for institutional unit or TRU. Relatively recent new accounts for energy-materials-pollution were integrated as satellite accounts for System for National Accounts (SEEA-SNA), which systematized the data on companies and localities, and partly took over the requirements of the Roegenian matrix for materials-energy-pollution (Georgescu-Roegen, 1971).

The problem of establishing spatial and temporal boundaries is expanding. The research direction to measure energy and materials consumption and related pollution has emerged. Georgescu-Roegen showed that the border issue is fine. The Life Cycle Analysis and Raw Materials Equivalents (RME) methods measure energy and materials (Schaffartzik, 2014; UNEP, 2010; UNEP, 2013) from cradle to grave. In the absence of spatial and temporal boundaries (SEEA- SNA) according to officially classifications, the amplitude of consumption can not be justified for partial (economic) processes. Under these circumstances, process comparison is difficult to be done. Although any analytical effort is justified knowing the energy and matter consumption supporting final decision of consumers (firms and individuals), dividing this consumption into the same spaces, firms and periods (or standard subdivisions) is necessary. Interests and patterns of behavior change can only be observed effectively spatially due to private / public ownership of the funds and flows of different agents (but spatially separate on different institutional units).

The classification of this information in the main general world databases (United Nations, Eurostat, OECD, FAO) for the level of companies and/or localities is the main argument for the preservation and use of official classifications. Classification becomes a requirement for saving effort and increasing the efficiency of using measurement in various decisions. Separate observation only on transport energy (and HH) is justified because it accounts for about 60% of consumption and pollution in the EU. A separate city-wide analysis of the two sectors (street and non-street) would allow unitary decisions for both public and private spaces (construction and non-street lands). These decisions could directly and appropriately influence an (appropriate) change of 2 different consumer segments.

The use of the Roegenian model based on this previous general description can assure the measurement of energy consumption and urban pollution in the case of a city (Timisoara) with spatial and temporal boundaries of the partial component processes (RTU and nano-zones). Consumption-pollution measurements with meaning without unnecessary complex coding - read without pseudo-measures (Georgescu-Roegen, 1971) - can provide greater support for decision-making than modeling and modeling decomposition aggregated measurements or complicated and uncomplicated coding. Some research shows differences between macro and micro measurements. It is necessary to remember that any macro date is based on sums of individual confidential data observed or modeled in some cases. But even the most rigorous aggregation may have inherent methodological inconsistencies. Index tests show the difficulty of aggregation for real economic processes. The principle of identity, the basic in the comparison of objects or processes, is undermined by aggregation, in the absence of passing the index tests. Validation on five levels by Eurostat is in this case partially met. For example, data reported by countries for expenditure consumption for HH (CP code) and implicitly for CP045 (energy for HH) and CP0732 (fuel individual transport) codes have been revised deeply (Eurostat, 2015).

The research aims to built an application of the Roegenian model to investigate the funds and flows for EO2P for vehicle energy consumption in relation to O2 production for four pTRU. The final task is to notice the neutral CO2 point for equilibrium for the four micro-zones in Timisoara.

2. Methods

The pRP for this research is TRU. The TRU are divided in public TRU (pTRU) for streets and sidewalk; the private TRU (prTRU) for HH and private artificial area (buildings and sidewalk) and natural land (garden). The modeling is made only for pRTU. The figures for neutral CO2 point /equilibrium for micro-zones (pTRU) will exclude the biased data by internal flows of pRP. The borders are the external (border) streets for every micro-zone and the length of day. The exact time for vehicle flow is 14 hours (to see footnote 1, map T03 with vehicle flows) and photosynthesis daily cycle for O2 production. The CO2 tree emissions are considered subtracted from O2 production as internal flow of pTRU. We assume only net O2 production from pTRU1. In other cases the old trees could be cut. A TRU is considered an urban micro-zone noticed as a pRP. The pRP is considered with temporal and spatial borders, and input-output flows. The pTRU are noticed separately for two micro-zones components: pTRU1 for trees and O2 flows; pTRU2, for vehicle and flows for energy fuel and pollution (EP). Some characteristics of flows are measured in Calculation and Discussion sections. The main Roegenian funds are considered the trees, vehicles, streets and sidewalks. The main agents are: HH, pedestrians, drivers and institutional units of City Hall.

The flows are: fuel flow (Ff) is input flow for pTRU/ pTRU2 and is measured as difference between initial stock and final stock from every vehicle tank; The Ff stock are recorded in input node and output node for every nano-zones. The nano-zones are streets and street segments for every micro-zones. CO2 is output flow for pRT2 and pTRU. O2 net flow is a output flow for Whole pTRU and pTRU1. The (net) CO2 flow of vehicle is a outflow for pTRU. The C/CO2 sequestration follows the chain of finesse nano-chemical processes of leaf photosynthesis. The chain of nano-chemical processes is next: O2 production; C sequestration; O2 capture from CO2 as glucide/sugar. The observation and metrics for equilibrium point of neutral CO2 follow this scheme. The description of pRP for this research follows the scheme of stylized facts. This scheme is compatible with Roegenian simile-model, based on metrics and adequate literal explanation.

The calculation is based on the next formulas with adequate explanations.

For pTRU1, O2 flow = ∑ tree leaf area i * C_{O2} , where i= 1, 2, …, n

O2 flow – flow of O2 , kg; tree leaf area i = surface of leafs for tree i

C_{O2} – the O2 production for every meter square of leaf; 0.02 and 0.0462 grams per day for variant V1/V2; n – number of trees for every nano-zone.

For the Whole pTRU the output flow is CO2 emission or O2 emission. The aggregate flows are the health and wellbeing- life enjoyment (Georgescu-Roegen, 1971) of agents. In our research is not discussed the sharing between CO2 of vehicles and CO2 of trees. CO2 of trees is considered internal flows for pTRU1. The O2 production for every component nano-zones of every micro-zone is aggregated. The all nano-zones for every pTRU1 are joined by external addition.

For pTRU2 the length of route i, Lri, for every nano-zones

Lri = Fvi * Lsi, where, i = 1, 2, …, n; i = street or street segment i

The Lri is calculated for two-way (one-way) for every nano-zones

Fvi – the vehicle flow for street (segment) I; Lsi – the length of route

For every pRTU2 the Lr is a sum of all Lri, Lr = ∑Fvi * Lsi

The CO2 emissions of vehicles, $CO2_V$, for every nano-zone

$CO2_V$ i = Lri * C_{CO2v}. The coefficient of CO2 emission per kilometer, C_{CO2v} for vehicle was used a average level by 0.162. For every pRTU2 the $CO2_V$ is a sum of all $CO2_V$ i. The net O2 production and net CO2 vehicle emissions for every nano/micro-zone are aggregated. The pRP of nano-zones of every pTRU1/2 are joined by external addition. It is assumed as O2 production for every nano-zone is greater as CO2 emission of all trees.

Database. The main figures are extracted from (Ciupa, 2005), PMT (PAED, 2014), City Hall Database (to see footnote 1, map T03 for vehicle flows), National Institute of Statistics of Romania and Eurostat. For nano-chemical reaction inside of leafs for the metrics of O2, C and C(O2) potential to be sequestrated, the transformation coefficients are taken according to (Ciupa, 2005) for variant 1 (for O2 production) and for variant 2 at half-level of a US report[3].

[3] https://www.itreetools.org/eco/resources/v6/reports/UGA_written_report.pdf

3. **Calculations**

The analytical framework of measurement and the landscape of pRP for four noticed micro-zones are further described.

Table 3.1 The street length and street vehicle flows, micro-zone Paroseni, 2010

Street	Street legth	Street flow	Route length	CO2 vehicle	Street	Street legth	Street flow	Route length	CO2 vehicle
Dragalina	130	5373	698	112	R	200	18195	3,639	586
Dragalina	130	11447	1,488	240	R	200	21588	4,318	695
Dragalina	200	5371	1,074	173	GARA	50	2506	125	20
Dragalina	200	11444	2,289	368	GARA	50	2525	126	20
Titulescu, N	840	6605	5,548	893	Jiul	150	979	147	24
Titulescu, N	840	7287	6,121	985	Jiul	150	292	44	7
Republicii (R)	590	20281	11,966	1,926	*Muresan A*	206	5,549	1,143	184
R	590	17558	10,359	1,668	*Seiler A*	178	5,549	988	159

Note. In italics, secondary streets.

The volume of the canopy is in 2010 for Paroseni Area of 34,231 cubic meters. It is calculated with a 3% annual increase starting in 2000. The total O2 volume is 685 kg daily, in the warm season (vegetation) in variant 1 (Ciupa, 2005) and 1581 kg in variant 2, with half of average of 92 grams). The volume of CO2 emitted by vehicles is 8062 kg daily, which 7,719 kg for main streets (no italics). Volume C sequestrated is 2199 kg, respectively 2105 kg for main streets. The volume of CO2 / C capture associated O2 emissions are 941 kg, respectively 257 kg.

For the other three micro-zones the figures are next. The volume of the canopy is in 2010 for Tineretii Area of 51,511 cubic meters. The total O2 volume is 1030 kg daily, in the warm season (vegetation) in variant 1 and 2,380 kg in variant 2. The volume of CO2 emitted by vehicles is 7,450 kg daily, which 6,643 kg for main streets (no italics). Volume C sequestrated is 2,032 kg, respectively 1,812 kg for main streets. The volume of CO2 / C associated O2 emissions are 1,417 kg, respectively 386 kg.

The volume of the canopy is in 2010 for City Hall of 373,257 cubic meters (with parks). The total O2 volume is 7,465 (with parks O2 contribution) kg daily, in the warm season (vegetation) in variant 1 and 17,245 kg in variant 2. The volume of CO2 emitted by vehicles is 2650 kg daily. Volume C sequestrated is 723 kg. The volume of CO2 / C associated O2 emissions are 10,265 kg, respectively 2,799 kg.

The volume of the canopy is in 2010 for UVT-UPT Area of 22655 cubic meters total and 11474 for the main street. The total O2 volume is 453 (229 main street) kg daily, in the warm season (vegetation) in variant 1 and 1,047 (530) kg in variant 2. We notice the canopy volume and O2 flows for every nano-zones. The volume of CO2 emitted by vehicles is 5,896 kg daily, which 5,084 kg for main streets (with no italics). Volume C sequestrated is 1,608 kg, respectively 1,387 kg for main streets. The volume of CO_2 / C associated to O_2 production is 632, respectively 170 kg only for street area. Additionally, for parks the volume of CO_2 / C associated to O_2 production are 1,122 kg, respectively 306 kg.

1. **Discussions**

The metrics of EO2P for the four pTRU are described in Calculation section. For the measurement was used a framework for pRP. The total volume of CO_2 vehicle emissions is 21,408 kg compared to CO_2 14,638 kg associated to O_2 production. The CO 2 neutral point is not achieved for every zone and for total all zones. Some (weak) correlation between the micro-zones measurement and the macro EU process is not proved. Also the street length aggregation for Timisoara is not in strong way proved. The next calculation is necessary to do the link between the figures found for micro/nano-zones and city Timisoara as pRP. The street length for Timisoara is about 570 kilometers[4]. The difference of 80 km compared to National Institute of Statistics figure ought to be justified. The length of all yearly vehicle routes inside of Timisoara is estimated using (PMT, 2014) about 0.9-1.3 billion kilometers. The numbers of vehicles in Timisoara is about 120 thousands having a length total as streets length. So the length of all vehicles is sufficiently for vehicle parking on one-way of the streets. The vehicle flow average and the route length is not consistently at a very weak estimation with the flow average for the main streets. A justification is maybe the length difference by 80 km.

The carbon (emissions) neutral point could now be fixed between two correlations. According to Ciupa (2005) the production of 8,5 million O_2 kg by Green Forest (the lung of Timisoara) is correlated to 3,195 kg of C sequestered. On the other side 3,500 meter cubes of estimation by C sequestered are related to a production by 9,8 million kg O_2. The estimation gap for the two basic figures is around 20%. The research of EO2P is done on parts of buildings, streets, types of vehicles. It is necessary to be supported by integration for the Whole process as city. Then integrated decisions are taken by mayors or local councils. One solution is to aggregate the figures found from research for the all urban micro-nano zones.

Macro levels of data will be validated in the future with the new metrics / measurements of micro-zones. In other sciences, the resumption of research is fundamental to changing the paradigm of research. Physicists struggle with intra-atom levels and permanently rebuild the knowledge gap between the known fragments: concepts, intra-atomic parts, etc. An analysis of micro-urban areas, incorporated into the Roegenian Whole to make up the macro level, appears to be the right solution. The resumption (again and again) of energy consumption and pollution research is justified, but with an even more precise integration, in order to know better the level of consumption. The metrics are accompanied by literal explanations according to the Roegenian model (Georgescu-Roegen, 1971).

The interest of agents is to reach the macro-targets as well the individual targets. We assume as individual target is sound with macro-targets, as 20-20-20 by example. Co2 neutral become a reference point and a target in some cases: for 20-20-20 (CofEC, 2008); for Covenant of Mayors. The metrics of pTRU1/2 at micro-level could

[4] http://www.primariatm.ro/uploads/files/nomeclatorstradal/dictionar_strazi_07_07_2015.pdf.

sustain better the dialogue between agents: HH, Local Council, institutional units of City Hall. Finally the metric underlie the Local Council decisions and the behavior change of agents for fuel energy consumption and decreasing of CO2 vehicle pollution.

2. **Conclusions**

For the first time the EO2P metrics were calculated for TRU for city Timisoara. The framework of modeling was for pRP. The borders of micro-zones and nano-zones assure the measurement of input-output flows. The funds of models generate the borders flow and internal flows. The internal flows are noticed but avoided for the final metrics. The external addition is used for the joining the Roegenian processes. The aggregations of flow metrics is made without to consider the internal flow. The input flows in Roegenian process becomes a process fund. By qualitative leap it becomes again an output border flow with other shape, name and effects. The fuel consumption becomes a CO2. The process of transport inside o pTRU is assumed. The photosynthesis process was noticed summary using pRP. The EO2P was measured using the main characteristics of flows and funds.

The metrics of EO2P was made for four micro-zones noticed as pTRU for CO2 emissions associated to fuel vehicle consumption and O2 production. The measurements is done using stylized facts only for Roegenian fund, streets and side walk, noticing the trees and the vehicles which cross the border pTRU. The amplitude between C capture and CO2 vehicle emissions is large for the two micro-zones and low for the other two micro-zones. To achieve CO2 neutral point for Timisoara ought to work all agents within Roegenian micro-processes. The total volume of CO2 vehicle emissions compared to CO2 associated to O2 production is 1.9 times. The CO 2 neutral point ought to wait to be reached for every zone and for total all micro-zones.

The O2 contribution for second TRU, the HH micro-zones, is very low, about 6% from pTRU (Ciupa, 2005). The CO2 emissions for HH and other buildings are 3.72 times greater vehicle CO2 emissions. Other researches will be started using pRP for HH sector. Some inconsistency between macro measurements and micro was found for street length and for the for the tree estimation for planting: about 13,000 trees according to Ciupa (2005). Other inconsistency could appear related to the range of CO2 emissions figures (PAED). The O2 production of trees estimated for planting on streets (pRTU) do not compensate the vehicle CO2 emission and carbon capture. The number of tree planting for CO2 neutral is approximate to be greater by 7-9 times more than inventory to 410 thousands trees (Ciupa, 2005). The measurement solution of 20-20-20 targets for every micro-zones is more realistic with real, not imaginary agents (Georgescu-Roegen, 1971). The mix solution to increase O2 productivity by new trees species with greater O2 productivity and the tree density to streets and parks, near to decreasing of vehicle flows appears to be more adequate. For temperate continental climate solution could be more viable for open TRU processes.

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Boosting energy efficiency in Public Administration
Study case: "Palazzo della Farnesina"

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Abstract
Carried out by *Federesco* - the National Federation of Energy Service Companies – in cooperation with Unit II – Headquarters Real Estate Management, this work intends to propose the most efficient measures in terms of building refurbishment for the "Farnesina" Palace. This complex, located in Rome, is the second largest public building in Italy, hosting the headquarters of the Italian Ministry of Foreign Affairs. Our study identifies the main inefficiencies in terms of energy consumption in this building, as well as all eligible measures to improve its energy performance. Among the most effective solutions, we propose the installation of a trigeneration power plant, a building automation system and the substitution of the lighting system. Moreover, these measures are also analyzed in terms of energy and environmental benefits, useful to draw a possible scenario on CO_2 and toe reduction in the next years. Specifically, our project led to an estimated reduction in CO_2 emissions of almost 1.000 tonnes per year and 230 toe (tonnes of oil equivalent) saved per year.

1. BUILDING DESCRIPTION

Originally conceived as the PNF (National Fascist Party) headquarters in Rome, "Casa Littoria" hosts today the Italian Ministry of Foreign Affairs and International Cooperation (MAE).
Construction works officially began in 1938, while external walls started to take form two years later. Lower rustic walls were the first to be placed and, in 1943, the marble-coated higher section of the building was completed. "Suspended" in the same year, construction works were resumed in 1951 with the total insulation of the building, the whole complex being completed in 1956 and expected to be fully operational in 1960. However, MAE units and departments were supposed to move to "Casa Littoria" one year before that date, being at that time roughly scattered between twelve offices in the city and the Prime Minister headquarter "Palazzo Chigi". For that reason, the whole building, originally designed for the PNF hierarchy and party structure, has been readjusted and completed in 1959 in accordance with MAE managerial, political and organizational needs.
The entire building is supported by a load-bearing, cement structure with brick masonry infill, coated with smooth travertine and rustic walls. On the façade, wide, steel-framed, single-glazed windows are equally distant one from the other. The complex has a floor surface area of approximately 99.725 m^2, with a 533.206 m^3 heated volume.

2. Energy consumption

2.1. Thermal energy

There are four gas meters in the building: one connected to the central heating plant; another one connected to two boilers installed on the roof, serving the Crisis Management Unit; a third one for the incinerator; the last one monitoring energy consumption in the kitchen area.
From November to April, methane gas consumption for central heating represents 98% of total energy consumption. Specific data for the 2012-2015 period are summarized in the table below (Table 1).

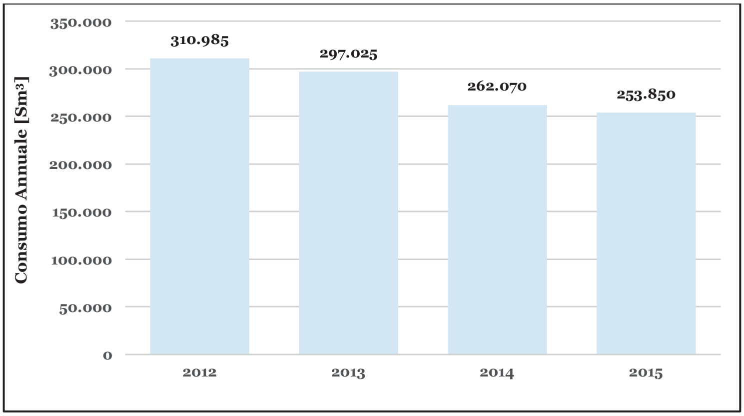


Table 1 – Annual gas consumption for the central heating plant (2012-2015)

On the other hand, many other heating devices are not included in the central system (fan coil units, heat pump air-conditioners), being directly managed by MAE staff and emplyees working in the building.
Finally, the remaining 2% of total gas consumption results from the energy used to heat up the Crisis Management Unit. Related data is reported below (Table 2) for the same period of the year.

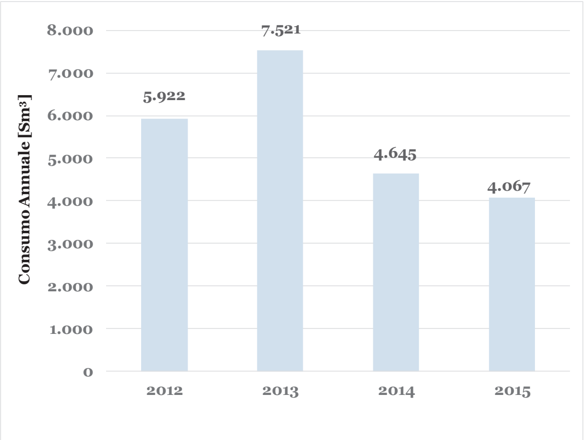


Table 2 – Annual gas consumption for the Crisis Management Unit (2012 – 2015)

2.1.1. Benchmark indices Analysis

Based on ENEA study on national energy consumption for office buildings (see: E. Santini, S. Elia, G. Fasano, "Caratterizzazione dei consumi energetici nazionali delle strutture ad uso ufficio", ENEA, 2009), the following table reports energy efficiency trends of MAE headquarters in terms of thermal energy consumption, which seem much lower than benchmark index.

Average annual consumption [Sm^3]	Surface [m^2]	Climate zone	Benchmark Index [$Sm^3/(m^2 anno)$]	Actual Index [$Sm^3/(m^2 anno)$]
286.522	96.000	D	9,00	2,98

2.2. Electric energy

Starting from 1.850 kW incoming electric energy for the whole building, total power consumption for each year between 2013 and 2015 amounts to 9.633.727, 9.511.409 and 9.673.897 kWh. Related data for 2015 are reported below (Table 3).

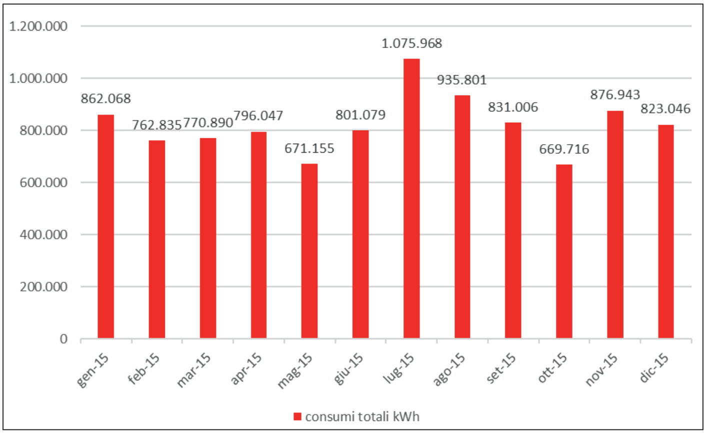


Table 3 – Monthly power consumption in 2015

Considering the average energy consumption for air conditioning during summer, July is estimated to be the peak period of electricity demand. In addition, some air conditioners have to keep working for the whole year when it comes to refresh those areas in the building where data server and racks are installed. On the other hand, the same peak demand is registered during colder months, which is mainly due to the lighting system.

2.2.1. Benchmark indices Analysis

As we did for thermal energy consumption, we hereby report ENEA energy efficiency trends of MAE building in terms of power consumption. According to these indices, the complex is considered energy efficient.

Average annual consumption [kWh]	Surface [m^2]	kWh/(m^2×year)	ENEA EE-Ranking
9.673.897	96.000	100,77	sufficient

2.3. Overview of installed plants

2.3.1. Heating System

The whole system runs depending on employees' working time (usually from 7.00 a.m. to 6.00 p.m.), from November to April, with 166 days per year.
The thermal power plant counts nine BIASI boilers of 1.511,9 kW each. All of them have been installed in 1990 and, by then, regularly fixed and maintained through several operations. Usually, only three of them are operational, while the other two are used as backup. Each boiler activates depending on its thermal load: once it gets too high, the second boiler starts working and so it is for the third one, normally during winter.

2.3.2. Cooling Systems

The cooling plant includes three McQuay, water condenser chillers, with a total capacity of 1.036,2 kW. However, more of them are currently installed elsewhere in the building in order to satisfy specific users' needs and to avoid energy loss in wide, empty spots of the building.
Considering all plants installed, the overall capacity is around 2.458 kW, with 1.021 kW, 2,41 Energy Efficiency Ratio (EER) electrical capacity. Moreover, there are around 700 autonomous, 2,6/3,5 kW mono-split air-conditioners for each room.

3. Main issues

3.1. Building structure

Since the beginning, MAE building has been often readjusted through a variety of interventions depending on users' needs. Precisely, several approaches and technological solutions have been adopted without a real perspective in terms of efficiency and building homogeneity. This is the case for window frames, which have been fixed in different ways while some of them still need maintenance in order to face the wind pressure coming from the South-West.
Most windows have thin glasses and single frames made of aluminum with no thermal brakes, with a total transmittance of 5,8 W/m^2K. The most critical issue is the difference in terms of thermal conductivity and insulation between the walls, which are in fact quite thick, and the window frames. On the other hand, walls structure easily prevents maintenance works on the heating system's pipes and components.

3.2. Heating System

Analyzing the heating system in terms of performance, the first problem we identified is strictly related to the building structure: some areas are too extended to be warmed-up, while smaller rooms are usually overheated. In this case, the whole system is considerably slow and therefore inefficient, especially at the beginning and at the end of the day. Moreover, additional devices, such as mono-split air-conditioners and fan coils, are often used to warm-up single rooms.

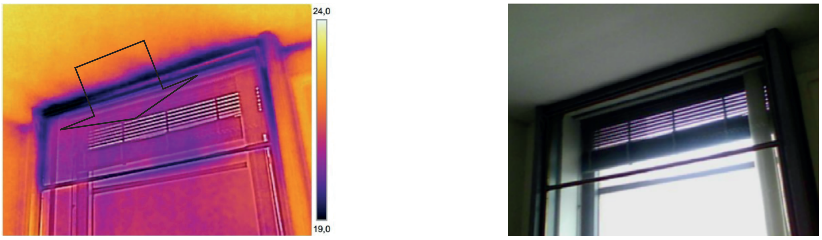
3.3. Cooling System

The cooling system is composed of one big central plant and other medium and low-capacity devices installed in several areas. The latter, being not connected to the central system, are difficult to manage and expensive to maintain and fix one by one, which implies a certain waste of energy and investments. Moreover, they are quite unaesthetic when installed on the external walls of the building.

4. Building requalification

4.1. Frame substitution

Major energy losses are generally located in the windows of the building envelope. Doors and windows are in fact very important for the heat balance of the complex as well as for the users' comfort inside the building. Besides air dispersion, air flows and solar gain, they are more frequently, as shown by our thermographic scans, the main cause of "heat bridges" and heat dispersion.



Picture 3 - Frame heat bridge

Frame substitution is usually adopted to save energy during both summer and winter, with considerable benefits in terms of users' comfort. Glass surface, which is approximately 9.400 m^2 in the whole building, represents 12% of the total building surface. In the following table, we report current data on window components as they are now and all eventual replacements related to requalification measures.

	Current status	*Proposed replacements*
Glass type	Single	Triple, low-emission
Frame type	Metal frame	Thermal-brake Aluminium
Window covering	Internal, Venetian blinds	Integrated, Venetian blinds
Glass transmittance [W/m^{2}K]	5,60	1,00
Frame transmittance [W/m^{2}K]	7,0	1,25
Total transmittance [W/m^{2}K]	5,82	1,10

Table 1 – Target windows for proposed measures

According to our analysis, expected savings for the heating system in terms of energy consumption are about 57%.

4.2. Requalification of the lighing system

Proposed measures include fluorescent and incandescent light bulbs substitution with LED lighting to reduce installed power from 687 kW to 345 kW. Considering that, now, their total annual consumption is around 1.939 MWh, the intervention would lower it at 969,5 MWh per year.

4.3. Tri-generation plant

For the CED area, a 165 kW cooling plant is installed, with a fixed thermal load 24 hours per day; moreover there is no fixed thermal load for the building. Such considerations brought us to propose a tri-generation plant, known as "combined cooling, heat and power" (CCHP), where recovered energy is redirected to an absorption-cooling plant producing cold water to refresh the CED room.
Specifically, a methane gas-endothermic engine would be arranged on a tri-generation structure with:

- 211 kW_e effective power capacity
- 267 kW heat output to be recovered
- 1,01 COP (efficiency rank) absorption-cooling plant with a 232 kW cooling capacity

Data on the CCHP plant performance per year are reported below.

Working hours per year [h]	8.400
Generated power per year [kWh_e]	1.754.700
Saved power for cooling system [kWh_e]	897.100
Remaining power to be recovered from grid [kWh_e]	7.224.900
Produced thermal energy [kWh_t]	2.220.400
Produced cooling energy [kWhfrig]	1.332.300
Required thermal energy [kWh_t]	4.490.700
Required fuel for the tri-generation plant [Sm^3]	467.000

Table2 – CCHP plant annual energy performance

Energy saving (TOE) and avoided CO_2 emissions are summarized in the following table.

Saved primary energy consumption/year [TOE]	130
Avoided tonnes of CO_2 /year [tCO_2]	57

Table 3 – CCHP plant energy saving and environmental impact

4.4. Automation, control and energy management of the 2nd floor

Proposed measures presuppose the elaboration of an automation, energy management and monitoring system (BACS – Building Automation and Control Systems), an EU Standard solution (based on CEI EN 15232 "Energy performance of buildings - Impact of Building Automation, Controls and Building Management") for the second floor of the complex.
Now, the existing system is classified as follows:

- Heating system control: D
- Cooling system control: D
- Lighting system control: D
- Window covering control: D/None

4.4.1. Cooling system control: From D to A-Class

A single air-conditioning device will be installed in every room/office at the second floor to directly manage their mode of operation and set them up on environmental standards. Temperature would also be easily monitored by employees and adjusted on "energy efficiency" modes, while all settings can also be managed through a web-based supervisory system. Finally, there will also be the possibility to include or exclude certain areas of the second floor depending on the presence of the employees and on external climate conditions. The cooling system will be therefore controlled and adjusted on specific needs and criteria, including those related to the main position of the room (North or South exposed).

4.4.2. Lighting System control: From D to A-Class

As for the cooling system, single devices will be installed in every room/office to optimize energy use. Specifically, occupancy and light sensors will be placed in every room, activating the lighting system only if needed. In addition, lights in corridors and common areas will be also adjusted through an occupancy sensor: they will be fully operational for five minutes or 40% less intense with no one crossing those areas.

4.5. Centralizing the air-conditioning system

As mentioned before, there are several air-conditioning plants installed on the façade. Besides esthetic considerations, some of them have very low EER standards, being commercialized many years ago and badly placed on external walls.

Given its extension, we propose to centralize not the whole system, which would be very difficult from a technical point of view, but specific sections in certain areas, specifically, the building façade. Used technology shall be air/air VRV (multi-split type air conditioner), replacing all internal splits with other units, 170 approximately, connected by area to five different VRV plants.
Related data on energy consumption before and after the intervention are reported in table 4.

Type of plant	Now	After intervention
EER	2,2	4,8
Annual power consumption [kWh_e]	424.000	194.333
Saved power per year [kWh_e]		229.700

Table 4 – Air-conditioning system performance before and after intervention

The following table reports general data on saved energy (TOE) and on CO_2 reduction for each year.

Primary energy saved per year [TOE]	43
Avoided tonnes of CO_2 per year [tCO_2]	80

Table 5 – Saved energy and environmental impact of Trigeneration plant

5. Conclusions

Considering all issues and challenges related to an energy efficient refurbishment of "Farnesina Palace", our study seeks to identify the most effective measures to be undertaken. For each intervention, we report in the following tables all costs and results in terms of energy saving and CO_2 reduction.

Intervento	**Investments**	**Saved power**	**Saved fuel**
	[€]	kWh_e	Sm^3
Frame Substitution	8.035.000		133.837
Lighting system	1.850.000	1.059.232	
Tri-generation (CCHP)	468.000	1.722.900	
Building automation	283.000	81.412	
Cooling system	520.000	229.700	

Table6 – Investments and energy performance of proposed interventions

	Electricity savings [kWh/year]	**Gas savings [Sm^3/year]**	**Primary Energy savings [TOE/year]**	**CO_2 avoided [tCO_2]**
Interventions	1.370.344	133.837	172	923
Tri-generation plant (CCHP)	1.722.900	-347.500	60	57
TOTAL	*3.093.244*	*-213.663*	*232*	*980*

Table 7 - Total energy performance

	Investments [€]	**Economic savings [€/year]**	**PBT [years]**
Interventions	11.380.000	336.516,00	33,1
Tri-generation plant (CCHP)	468.000	102.800,00	4,4
TOTAL	*11.559.681,81*	*403.388,00*	*28,7*

Table 8 – Economic savings after proposed interventions

Calculations do not include avoided costs related to maintenance works, such as frame and air-conditioner substitution; moreover, current frames have never been replaced and such measure would be soon necessary.

If in the short term proposed measures could not seem convenient in terms of economic benefits, necessary investments will be paid back in the long term, considering that the whole building is expected to be fully operational for the next fifty years. Moreover, with the Ministry of Foreign Affairs being a strong example in energy refurbishment, the Italian State Administration would gain in political visibility at the national and international level in the field of energy efficiency and CO_2 reduction.

Energy use in food supply systems: what are the reduction options?

Sanderine Nonhebel

About 20 % of the energy use in societies is related to the food supply system. This system includes the agricultural and livestock production, the storing, distribution and processing of agricultural products into food. In the agricultural societies, all these activities were conducted in the households themselves, in the modern industrialized societies activities are spatially separated. Agricultural production and the human consumption of the food can take place in different continents, requiring a lot of transport. Next to this consumption patterns have changed over time the modern diets (milk, meat, fruits, vegetables) require far more energy than the old staple food based menus, due to their cold storage requirements. Finally, the spatial separation makes that nutrient cycles are broken, since it is hard to return manure to the agricultural fields, when the livestock feed production and livestock raising is in different continents. The broken cycles make and extra mineral fertilizer (energy intensive) is needed to replace the manure used in the local systems.

It is obvious that the food supply system requires a lot of energy and it is of great importance to search for options to reduce it energy use, like this is of importance for for instance the transport system. There is one big difference here: the production of food is vital. We need a daily supply of food to stay alive. This makes the search for energy reduction options extra complicated. All energy reduction options should be analyzed on their effects on food security.

Next to energy the production of food also requires water and land, these two resources are also scarce and options on energy use efficiency should also be evaluated on the impacts on these resources. Urban agriculture for instance will reduce the needs for energy in the food system, however since there is very limited space available within cities the contribution of urban agriculture to the total food needed is very small and therefore the energy reduction that can be achieved by urban agriculture will be limited.

This presentation will discuss the transitions in the food system in the last century and the impacts of these changes on the energy demands. Then it will indicate the processes requiring a lot of energy and the options to reduce energy. Finally impacts of these reduction options on food security and land and water use will be evaluated.

Smart urban energy systems: From a playground for ‘the cities of the future’ to long-term solutions for viable cities

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Extended abstract

The ambitious goals to substantially reduce greenhouse emissions so that global warming is limited to 1.5 °C above pre-industrial levels [1] and at the same time secure access to clean, reliable and affordable energy for the world’s population [2] requires significant efforts to transform energy systems. This includes a dramatic shift from fossil fuels to renewables, a major increase in energy resource efficiency and decoupling economic growth from environmental and climate impact through systems innovation and change to more sustainable consumption patterns.

Transition to sustainability for energy systems in cities is recognised as crucial for transforming to a net zero emissions global economy [3]. More than 54% of the world’s population currently live in urban areas and cities continue to attract new inhabitants due to better access to employment, social services and education [4]. While cities are prized for being motors of innovation, social experimentation and economic growth, rapid urbanisation brings major social and environmental challenges. With increasing density and complexity of all elements of the energy system, e.g. energy generation and distribution systems, transportation, consumption of food, goods and services, waste handling, supply of fresh water and other ecosystem services, cities are responsible for more than 60% of energy consumption and generate an estimated 70% of human-induced greenhouse gas emissions, heavily contributing to climate change [5]. Thus, cities have a central role in reaching sustainable energy and climate goals.

The rapid deployment of ICT is recognised as a facilitator of the transformative power of urbanisation towards sustainability [3]. The diffusion of ICT and digitalisation, in combination with the shift toward an information society and ubiquitous computing, are giving rise to new possibilities for automation and optimisation of urban energy systems; integration of electricity, heating, waste and water infrastructures and transport systems; and new opportunities to transform daily and economic life and to facilitate innovation and co-creation.

Acknowledging ICT as an essential enabler of the transition to sustainable urban development and a zero net emissions society, the concept of ‘smart sustainable cities’ has been introduced and is rapidly gaining momentum internationally [6]. By ‘smart’ is meant the connection and integration of intelligent physical infrastructures and the engagement of human capital in planning, decision-making, innovation, coordination and behavioural contributions, as well as governance and collaboration models and processes and financing and business models. The term ‘sustainable’ refers to all aspects of urban sustainability (environmental, social and economic) [7].

Internationally recognised cities implementing and testing smart city technologies include Vienna, Toronto, Paris, New York, Stockholm, Tokyo, Berlin, Cape Town, Copenhagen, Hong Kong, Barcelona, Amsterdam, Melbourne, São Paulo, Seoul, Vancouver, etc. Forerunners, so-called “cities of the future” [8] or “lighthouse cities” [9], admittedly play a vital role in paving the way to a sustainable future (through making ambitious climate and energy commitments, developing long-term sustainability strategies and facilitating systems change, technology and social innovation, policy-making, environmental protection etc.). However, we argue that major research and innovation efforts should be tuned toward replicability and scalability of smart city (and smart energy) solutions, to enable viability of cities globally.

We have coined the term ‘*viable city*’, inspired by metaphors from biology and medicine, where *viability* loosely means capability for living, growing and developing, especially under particular environmental conditions. For cities as complex systems of systems, viability may be introduced with the meaning that *“the different components and functions of a dynamic, stochastic system at any time remain in a domain where the future existence of these components and functions is guaranteed with sufficiently high probability”* [10]. All cities are faced with tremendous challenges arising from rapid population growth (or shrinkage), declining outer economic hubs, environmental degradation, climate change, segregation, societal inequalities and the ever-increasing expectations of city services from citizens and businesses. Thus, for a city to be viable, a number of viability constraints (e.g. social, environmental, economic, physical etc.) must not be violated. To this end, smart (ICT-enabled) solutions can facilitate the multiple qualities of cities, such as adaptiveness, resilience, responsiveness, but also liveability, attractiveness and others. It should not be forgotten that the viability of the world’s cities requires cities to take responsibility for their global production and consumption footprint [7].

The creation of smart sustainable cities requires a cross-sector, transdisciplinary, multi-stakeholder approach, which calls for the establishment of strategic collaborations between pubic authorities, industry, academic institutions and civil society. In Sweden, one such quadruple-helix consortium with about fifty partners has designed and is currently running the strategic innovation programme “Viable Cities” to support Swedish and EU energy and climate commitments and to reinforce sustainable growth by facilitating the transition to smart and sustainable cities [11]. Through research, innovation and coordination activities, the programme aims to support system-level innovation and structural change, including changes in governance, business relationships, infrastructure and urban form. The programme takes a people-centred approach through empowering citizens and utilising co-creation to drive energy and climate agenda.

While developing the “Viable Cities” programme, analysis of existing initiatives clearly showed that there are excellent examples of energy- and climate-smart solutions in Swedish cities and internationally, but that leveraging the experience and learnings can be improved dramatically. Examples of solutions include those related to heating and cooling networks, waste management, electric buses, energy-efficient buildings, smart grids, public transport networks, carpooling etc. Partner city authorities and companies emphasised the challenges and need for greater replication and scale-up of solutions that have been successfully demonstrated in one part of a city, as well as transfer and exchange with other cities to achieve national and global outreach.

To conclude, recent studies and interviews with partners of the "Viable Cities" programme confirm that there are high expectations on ICT to support sustainability transition of urban energy systems, quality of life, innovation and investments. However, the full potential and consequences of ICT deployment (e.g. rebound effect, risks and vulnerabilities, security and privacy and other ethical issues) are not yet well understood, and should be systematically studied and critically evaluated to secure viability of cities in Sweden and globally.

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Emergy Accounting System Modeling of Urban Water Metabolic Systems

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Abstract

We adopted the latest emergy baseline value, constructed the urban domestic water supplying process metabolism model as well as accounting framework; then analyzed the whole process of the supplying of domestic water from four sources for Beijing (surface water, ground water, water of the South-to-North Water Transfer Project, SNWDP; potential desalinated water from Tianjing) with emergy synthesis. The results show that the emergy input of transportation, treatment and distribution of water from the above-mentioned four sources are 5.14 E+12 sej, 7.15 E+12 sej, 6.49E+12 sej, 67.03E+12 sej respectively if the final user could obtain 1 m3 tap water; and the value of sea water is 13 times higher than that of surface water, the value of SNWDP water is not much higher than that of surface water; from the whole supplying process, the emergy input of treatment process is higher than the other two phrases. Additionally, some policy recommendations for the sustainability for Beijing domestic water supply are also put forward. Finally, after summarizing the potential improvements, the future researches are prospected.

1. Introduction

Finite water resources facing many communities, generally increasing demands and aging water infrastructure are some of the greatest challenges for China and many other global regions. Nowadays, urban water metabolism is one of the primary tasks of all mankind to scientifically protect and reasonably utilize water resources. However, due to rapid population growth, economic development, and climate change, global water has been under great pressure. The rapid increase in water demand and the reduction of the fresh water supply have resulted in water shortages becoming a serious problem in many countries (Wang et al., 2016). The United Nations Educational, Scientific, and Cultural Organization (UNESCO) predicts that global water demand will increase by 44% in 2050, with residential water growing nearly 1.5-fold (UNESCO, 2014). Without a constant supply of water, human society cannot smoothly and continuously develop (Chen et al., 2016). Besides, the Safe and Sustainable Water Resources (SSWR) research program in US EPA is conducting research and analyses that strive for solutions to ensure future generations will have adequate water of sufficient quality. The research program developed sustainable solutions by integrated transdisciplinary research addressing social, environmental, and economic outcomes. The complex water issues cannot be sustainably solved by the traditional "siloed" water management approach. In a water-connected world, sustainable solutions have to require a system-based approach, in which water services (traditionally within wastewater, stormwater, and drinking water) are integrated with the efforts of maximizing the recovery of resources (energy, nutrients, materials, and water). The related SSWR researches intend to use holistic analyses of water resource and water infrastructure that provides the full life-time, water system assessments at the same time to avoid transferring issues from one problem area to another. Next-generation sustainable water systems should employ effective water management practices, which provide safe and sustainable water from source to drinking water tap to receiving water. Further, these water systems need to be adaptive so as to address changing societal aspirations, demographics, and climate.

Beijing is located in the northern portion of the North China Plain, and its water sources mainly come from surface runoff and groundwater water produced by precipitation (Ni et al., 2001). With population agglomeration, the rapid development of the economy, and especially the third industry (the service industry), Beijing has already become a seriously water-deficient area in China. The sharp contradiction between water resource supply and demand must be addressed promptly. In early 2014, President Xi Jinping of China visited the Ministry of Water Resources in Beijing to investigate the situation. He outlined important instructions for water construction in the new situation, clearly stating that the, “City should adhere to the principle of determining water supply according to the city, place, population and production.” He indicated the transformation from “supplying according to demand” to “consuming according to supply.” Therefore, planning should transition from purely considering water amounts to comprehensively considering input, efficiency, and sustainability in the water supply process.

The value analysis method provides a good approach for such an undertaking. According to the study of Hu et al. (2013), the majority of the water consumption in Beijing is due to family use, i.e., domestic water. Before the operation of the south-north water Transfer Project in 2014, Beijing's water mainly came from the local surface water and groundwater. However, this limited supply cannot meet the demands of Beijing. As an “alternative source” of traditional surface water and groundwater, the south-north water Transfer Project greatly alleviated the pressures on the Beijing water supply. From the perspective of economy, some scholars have attempted to minimize the water network input costs, annual input, construction and energy input, total input, and greenhouse gas emissions via many methods such as a genetic algorithm (Gupta et al., 1999; Prasad, 2010), nonlinear programming (Gomes and Silva, 2006), integer linear programming (Samani and Mottaghi, 2006), quadratic programming (Bai et al., 2007), a multi-objective genetic algorithm (Wu et al., 2012; Vamvakeridou-Lyroudia et al., 2007), a multi-objective hybrid algorithm (di Pierro et al., 2009), random transmission algorithm (Bolognesi et al., 2010), and a multi-objective particle swarm optimization algorithm (Montalvo et al., 2010).

One of the system-based methods is emergy synthesis. Emergy synthesis method has been used for various systems at multiple scales to incorporate environmental, social, and economic aspects into a common unit of nonmonetary measure (solar energy equivalents) and objectively assess the sustainability of the systems. It not only quantitatively assesses the direct and indirect energy required to produce goods and services but also provides managers a decision criterion to evaluate the efficacy of alternatives. For example, at the drinking water supply and distribution level, emergy will provide a unique holistic aspect of the system that capture the natural capitals in the background supporting any economic system, such as the “free” contribution of rain to the economy. Emergy can be used to evaluate the impacts of the following in terms of overall system efficiency: dual water quality, nutrient and energy recovery, natural green infrastructure, aquifer storage recovery, and regional water allocation. This method has the potential to integrate sustainability principles to water system management at different scales and levels. This method is often compliment to and integrated with other system metrics such as life cycle assessment (LCA). It is obvious that a large number of engineering and construction investments on the project will inevitably increase the water supply cost, regardless of the economic costs or energy inputs measured from the perspective of emergy, and the cost will be higher than that of the local water supply. So, how high is the cost? Water desalination is a different life alternative water source in the long term. Which unit volume of emergy is lower, water from desalination or from the project? What is the emergy input of the two local water sources and alternative water resources in each process of water mining, allocation, processing, and end-user arrival through the municipal pipe network? It is beneficial to clarify the above issues from the viewpoint of emergy and provide suggestions for rational planning and configuration of domestic water in Beijing. Conceptually, domestic water is comprised of water used by residents and by the municipal public construction (Yuan, 2004). From the perspective of emergy, Zhou et al. (2013) estimated that the water system energy consumption accounts for ~10% of the total urban energy consumption. Energy consumption depended on water resources, population, climate, and other factors. Water extraction, processing, and transmission require electricity (Ramos et al., 2011). It was estimated that 2-3% of power consumed in the world is applied in the water supply system (Alliance to Save Energy, 2002). In Brazil, it took an average of 0.862±0.046 kWh electricity to accommodate 1 m3 of water production and supply. Thus, Brazil's direct electricity consumption by the water supply system accounted for >1.9% of its national power consumption in 2012. Due to water loss in water supply systems, 30% of the power was wasted (Vilanova and Balestieri, 2015). This indicated that water loss both wastes water and results in useless energy consumption. Cheung et al. (2013) suggested that the energy efficiency of the water supply system of tall buildings could be improved by a new optimal design in tank location.

The existing research involves supply facilities scale (e.g., such as water supply plants and sewage treatment plants), the entire process scale (e.g., such as water supply, water division, and sewage treatment), and the regional scale (e.g., city, province, and country) (Lin, 2015). Using life cycle analysis, Raluy et al. (2005) compared the expected energy consumption of the Transfer Project on the Obo River in three different situations in the Spanish national hydrological planning. Nalanie and Robert (2006) used the life cycle method to explore energy consumption and CO2 emissions of the water supply network system of Auckland, New Zealand. Lundie et al. (2004) predicted the water supply’s influence on the environment in Sydney, Australia in 2021 using life cycle analysis. Stokes and Horvath (2011), and Lyons (2009), respectively, used the life cycle analysis method and hybrid life cycle analysis to study water energy consumption and its influencing factors in different water supply plants with different water sources. Venkatesh et al. (2014) performed a case analysis of Oslo, Nantes, Toronto, and Turin to investigate energy demand factors per unit of water, water treatment, water distribution, and sewage treatment, calculating the proportion of the water unit of energy demand and carbon emissions in the entire water system.

2. Materials and methods

Urban water supply engineering systems in Beijing include obtaining water, water purification, water transportation, and water distribution (He, 2009). Currently, urban water can be obtained from surface water or groundwater through water pumps, processed in a water treatment plant or water plant, and then distributed to each user through the urban water supply pipe network. Tap water supply processing requires material, energy, labor input, and corresponding facilities.

According to the traditional energy analysis procedure, the research boundary of this part was identified as the session from the source water entering the water plant to the source water being processed into the supply network, after which a system emergy map was drawn based on the emergy circuit language created by Odum (the energy map of this part including the process before and after the treatment.

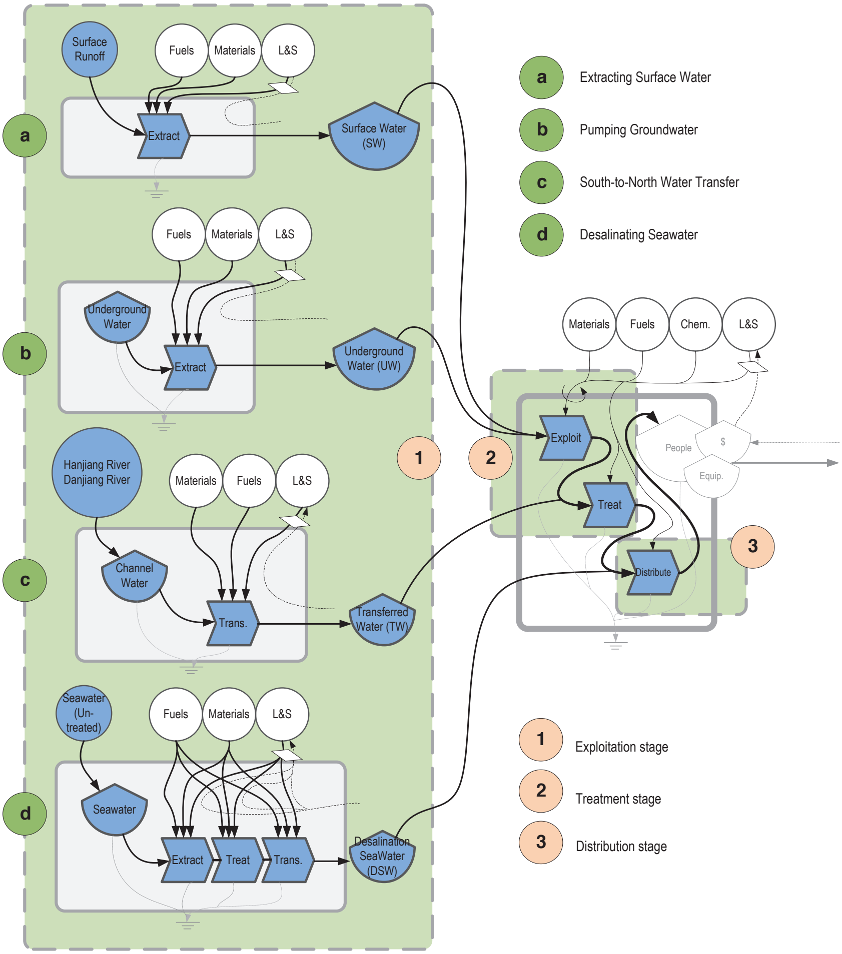

Fig. 1 Emergy diagram of urban water system in Beijing

3. Results and discussion

The source of the water supply is not always clean, and the source water must be treated to alleviate peculiar smell, enhance purity, and eliminate pathogenic bacteria. The worse the quality of the source water is, the higher standards would the water treatment require, which means the cost is higher (Buenfil, 2001). The following is the energy analysis of the water treatment of four types of water sources for domestic water consumption in Beijing. Following it is the creation of the emergy analysis table. Last, there is calculation and index analysis.

Prior to 2000, the annual emergy driving the geobiosphere was calculated as 9.44E+24 seJ/yr (Odum, 1996) as the sum of solar radiation, deep heat and tidal momentum (calculated as solar-equivalent amounts). Odum et al. (2000) recalculated the total emergy baseline as 15.83E+24 seJ/yr to include the co-activities of solar, gravitational and geothermal sources. Previously calculated UEVs must be multiplied by 1.68 (the ratio of 15.83/9.44) for conversion to the new baseline. Brown and Ulgiati (2010) refined this calculation to 15.2E+24 seJ/yr based on updated values and the conversion of energy to exergy units. The emergy baseline is the reference for all main biosphere-scale processes, the UEVs of which are also calculated under this assumption to set the UEV of solar radiation equal to 1 seJ/J. All other UEVs of human dominated processes are calculated accordingly as the ratio of the required emergy input flows to the output flow(s). In this study, we choose 15.2 E+24 seJ/yr as the annual emergy global baseline, based on Brown and Ulgiati (2010). Unit Emergy Values (UEVs) calculated according to Odum (2000) baseline can be left unchanged, because the difference falls within the uncertainty range of the Brown and Ulgiati (2010) baseline, as pointed out by these Authors; UEVs calculated before the year of 2000 (9.44 E+24 seJ/yr baseline; Odum, 1996) should be multiplied by 1.61.

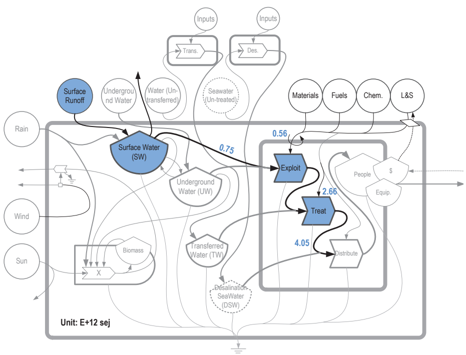

Fig. 2 Emergy diagram of surface water treatment (per m^3)

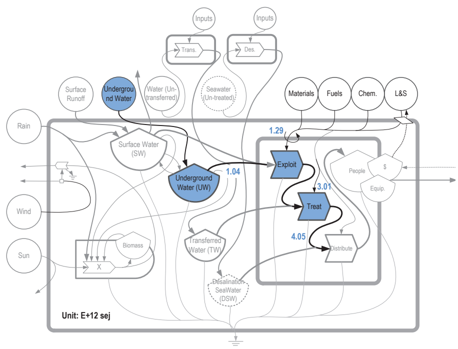

Fig. 3 Emergy diagram of ground water treatment (per m^3)

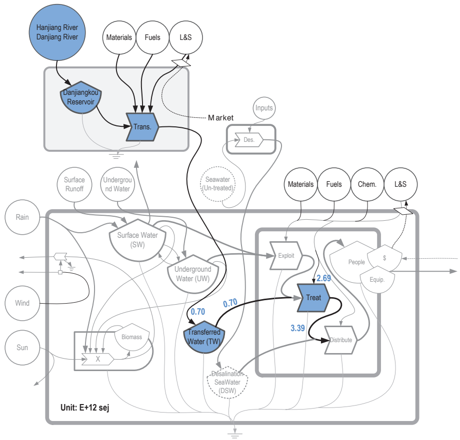

Fig. 4 Emergy diagram of SNWDP water treatment (per m^3)

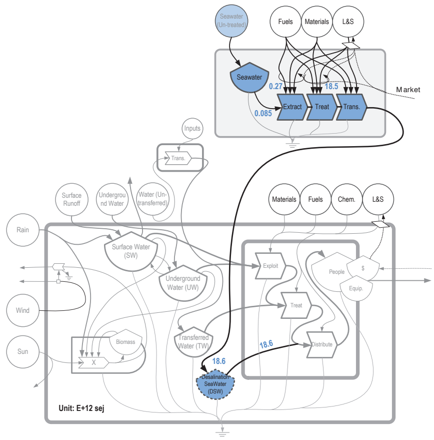

Fig. 5 Emergy diagram of sea water purification treatment (per m^3)

Table 1 below was created based on the following formula: (Arbault et al., 2013) and the energy amount Einput (ratio between total purchased emergy (F) and water output)

$$EYR = 1 + R/F \quad (1)$$

$$ELR = F/R \quad (2)$$

Table1 Emergy indicators of the four water treatment processes

	Surface Water	Underground Water	South-to-North Transferred Water	Desalination Seawater
EYR	1.28	1.35	1.26	1.00
ELR	3.57	2.89	3.84	2.15E+02
EmSI	0.36	0.465	0.33	4.66E-03
E_{input} (E+12 sej)	2.80	3.54	2.83	44.00

As per Table 6, the EYR value of processing underground water is the highest, whereas that of processing seawater is the lowest. This is because the UEV value of ground-water is comparatively higher, while that of seawater is the lowest. The ELR value of seawater is the highest (much higher than the ELR value of the other water sources), and the ELR value of groundwater is the lowest, all of which match with the differentiated level of their UEV value. Comparing EmSI values, which are characterized sustainable indicators of the treatment process, the EmSI of groundwater is the highest, and that of seawater is the lowest, with the difference between the former and the latter reaching two magnitudes. Considering Einput, the value for seawater (the highest) is 15.7-fold that of surface water (the lowest). From a holistic perspective of all four indicators in Table 6, the indicators for surface water and inflow water to Beijing are not much different because the inflow water to Beijing is also surface water, and the water quality conditions of inflow water to Beijing and the local surface water are similar.

4. Conclusion

Based on the research in this article and from the perspective of energy input, the water source from the south-north water transfer project is superior to that from the potential desalinated seawater from Tianjing in terms of the alternative water source for Beijing's domestic water consumption. Regardless, saving water is more important than transferring water, and we should strengthen the optimization of reservoirs' operational capacities and address an optimized design for pipe passageways and water networks by following the principle that high quality water should be used in important places and working on a dual water supply and versatile utilities of water (Vilanova et al., 2014). Using the water from the south-north water transfer project contributes to the shift of the model, in which Beijing turns from primarily relying on the supply of groundwater to mostly resorting to the supply of surface water. As a result, it becomes possible to regulate the water supply, gradually recharge the groundwater, and improve the urban environment.

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