Solar Energy Prosumption in Fruit Value Chains Support the Energy Transition

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Abstract. The objective of the present study was to assess the potential of reducing carbon emissions from on-farm energy use for fruit storage. For this case study, we developed a model fruit farm, where apples are produced, then stored for up to six months and sold on the local market. We calculated the primary energy demand and the carbon footprint of solar versus national grid energy to operate the fruit storage. We determined the extent to which the use of solar energy would contribute to the decarbonisation of the fruit value chain at the farm level under the given energy requirements. In our study, we compared the carbon footprint for two scenarios: Use of i) self-generated solar electricity and ii) grid electricity.

The main challenge when considering the use of solar energy is that energy is needed for the storage facility in winter, when the yield from solar energy is lowest, and a high yield from solar energy is achieved in summer, when the energy demand on the farm is comparatively low. This is true not only for fruit farms, but they represent one of the most energy-intensive forms of agricultural production.

We argue that while the use of alternative energy sources compared to the normal grid has a positive environmental impact on reducing carbon emissions, the temporary gaps in solar energy production and demand contribute significantly to farmer uncertainty. Based on our calculation we can show, that there is most probably no additional financial burden on farmers.

Keywords: Apple; fruit storage; green energy; sustainability; solar panel

1 Introduction

In order to support the energy transition and reach the goal of achieving an energy supply with low carbon emissions by 2050 at the latest, a leverage point in the pome fruit value chain is to sustainably procure the energy to operate the storage facilities of pome fruit. Until a few years ago, the principle of using the sun for growth on a farm was limited to growing crops, but due to technological advances and rising energy prices, it is becoming more and more interesting for farmers to also think about using the sun to produce the energy needed for the processes on the farm from field until the farm gate. To combine the production and consumption of a resource at the same location can be associated with several benefits. It is important to have a look at the farmlevel and its potential for energy prosumption due to the availability of un- or underused spaces e.g. on roofs. Alvin Toffler coined the term *prosumer* in 1980 for individuals who simultaneously assume the role of both consumer and producer, partially or completely (Toffler, 1980). Our study considers the sustainability potential for energy prosumption in the fruit value chain at the farm level.

In this case study, we designed a model fruit farm in Germany with apple as the dominant crop as an example and investigated its potential in terms of CO_2 savings and financial benefits in the event that alternatives to the conventional power grid are used for energy supply for fruit storage. In Europe, apples are one of the most cultivated fruit crops with 10-12 million tons per year (Eurostats, 2022). Apples are also an important nutritional source of vitamins and minerals, consumers expect to buy apples all year round for a healthy diet. Therefore, the retailers try to cover the demand in months without domestic or European apple production, especially in the months of May-July, with imports from the southern hemisphere (SH). The three most important apple imports from the southern hemisphere to Germany come from New Zealand, Chile and South Africa, with New Zealand and Chile challenging each other for first place depending on the annually fluctuating yields. In New Zealand exported over 35,000t to Germany, alongside Chile (36,000t) and South Africa (10,000t) showing the slight yearly variations depending on the season (Statista, 2022). The harvest on the SH begins in February, so apples from the south can be made available directly after transport from April without energy-intensive storage.

Previous studies have shown (Blanke and Burdick, 2005; Milà i Canals et al., 2007; Frankowska et al., 2020) that it is highly advisable for consumers, to source regionally cultivated apples and other fresh produce locally for most of the year. The calculations of the primary energy demand of domestic apples have shown that the energy balance of domestic and marketed apples from October to April is more favorable from a sustainability point of view than that of imported apples from the southern hemisphere. This is despite the energy required for storage, which is the most energy-intensive process in the supply chain to keep the local fruit in good quality and marketable condition for an extended period of time. But there is a challenge between consumers demands and producers possibilities, most local pome fruits in the North are already consumed by the end of April and cannot meet consumers demands.

To maintain all year-round fruit supply, local apple can be stored after harvest, from October to April in the northern hemisphere (Koca, 1993; East et al., 2013) and are complemented with apples from the south from April until the beginning of the harvest in August. The apple storage is under a controlled atmosphere (CA) of 1-3 % CO_2 and 1 - 3 % O_2 at temperatures of 1-3°C (Yost, 1984; Doerflinger et al., 2015) and requires 0.81 MJ/kg primary energy for 7 months (~0.172 MJ/kg/month) thereby contributing ca. 20-30% to the overall energy balance of the product (Blanke and Burdick, 2005). When harvesting in the global south begins in February and apples harvested there are on sale in Europe from April, conditions change from April onward in two ways. First, stored stocks of domestic apples begin to run low, and second, the energy required to store apples adds up to be comparable to the energy required to transport imported apples. This energy ratio of imported to domestic apples remains even if one assumes technical efficiency gains, which experts estimate to be about the same for both variants (pers. comm.). Thus, the absolute numbers may have changed over the past 15 years, but the ratio of primary energy consumption is still comparable. The question therefore arises as to whether and how the energetically more favourable supply of regional products can be maintained for longer.

While the primary energy balance could be improved by the installation of energy-saving equipment for cooling and storage of fruit or an innovative storage regime which works with higher storage temperatures and optimized ventilation of the storage chambers (Kittemann et al., 2015; Neuwald et al., 2015), we argue that the carbon footprint of the energy used can be reduced by a sustainable choice of the energy source.

Assuming that a more favourable CO_2-balance can be achieved for the same primary energy requirement for apple storage by switching to e.g. solar energy, the eco-balance of regional fruit could also be more favourable than that of imported fruit in the harvest months in the southern hemisphere. We therefore compare the carbon footprint of local apples with the carbon footprint of imported apples from New Zealand, depending on the energy source for the storage facilities. Our approach also calculates the potential savings of fossil energy from the German power grid on regional fruit farms through the use of photovoltaic systems (PV) on the roofs of the fruit stores and the potential savings on CO_2 due to the use of green energy.

While many farmers are interested in more sustainability and want to use sustainable energy sources for fruit storage, they can be hesitant due to the uncertainty of if and when the investment will ever pay off. Therefore, another objective of the present work is to give an estimate of the expected net financial gain of using solar panels for a more sustainable horticultural production. Probabilistic decision analysis approaches are used ex-ante in cases of decisions with high uncertainty and risk in the presence of poor or insufficient data to provide a more accurate estimate of the risk and likely outcomes of the decision (Luedeling and Shepherd, 2016; Do et al., 2020). We use a probabilistic decision analysis approach to estimate the investment risk for the farms.

It is our hypothesis that the use of green energy for the storage facilities can significantly contribute to further improving the overall carbon footprint of regionally grown and locally consumed fruit and contribute to the income of the farms.

In summary, the study examines the role of farmers' sustainable decision making and how the farm and the society alike might benefit from a good outcome of the decision. Two scenarios compare the impact of replacing the energy source for the necessary processes on a fruit farm and its implications for the carbon footprint of the final product, domestic apples with i) grid energy vs. solar energy ii) domestic apples in fruit stores powered by solar energy versus imported apples from overseas. The findings can be used to provide substantial producer and consumer information and guide social actors to make more sustainable choices.

2 Materials and Methods

2.1 Conceptualising the model fruit farm

We designed a model farm located in the Rhineland growing region of Germany, producing for domestic demand (Table 1). The system's boundaries were set around the post-harvest and storage (Figure 1). The model fruit farm was designed according to the average values for the Rhineland region (Table 1), its apple acreage was taken from the German Federal Statistical Office (DESTATIS, 2017). The data refer to the status as of 2017, the year of the fruit tree census, which will only be updated by the end of 2022 at the earliest. Apple yields per hectare from the state office of North Rhine Westphalia were averaged over 5 years (2015-2020) as basis for the required CA storage capacities, assuming that the storage capacity is 10% in addition to that required for storage of the average annual harvest volume. The roof areas of randomly selected farms in the Rhineland were measured on maps available online. Based on the requirements of the calculation tool PVGIS regarding orientation and inclination, the percentage of roof area suitable for PV systems was estimated. On this basis, it was determined that each farm in the Rhineland would have at least 1000 m² of suitable roof area. With an efficiency of 20%, the construction of a PV system with 200 kWp would be possible for the farms. The goal is to investigate what proportion of the electricity needed to store the apples can be covered by the solar system during the 7-month storage period.

Table 1: Data for the model fruit farm in Rhineland region (Germany)

Parameters	Value
Latitude [°N]	50.6
Apple production area [ha]	16.9
Yield per unit area [t/ha]	32
Yield per unit time and farm [t/a]	540.8
PV-usable rooftop area [m²]	1000
CA storage capacity per farm [t]	600
Nominal capacity of PV system [kWp]	200

2.2 Flowchart and system boundaries

For the primary energy analysis, we focus on post-harvest processes on farm. The system boundaries of the present investigation exclude all other energy requirements e.g. during fruit production and all steps necessary after storage until marketing to the end-consumer (Figure 1). The primary energy analysis (PEA) includes all stages from after harvest to the end of the storage period. The present investigation and energy requirement starts from freshly harvested apples at ambient orchard temperature (14-18°C), which need to be pre-sorted and then cooled down to the final storage temperature (1-3°C). For the imported apples from overseas (New Zealand), all energy requirements starting from cooling down, followed by transport from overseas until unloading in Antwerp until the transport to the Rhineland in Germany are included in the calculation.

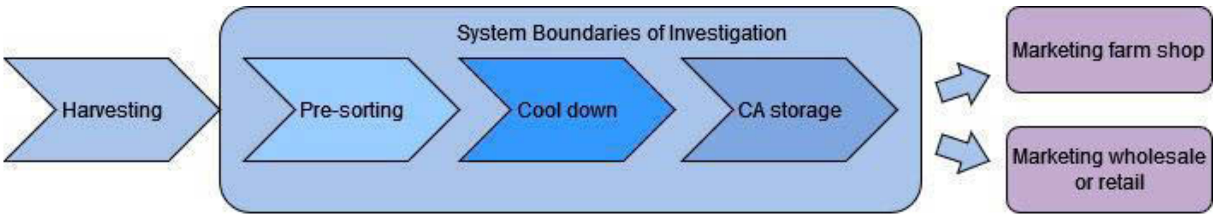

Figure 1: Flow chart and system boundaries of the primary energy analysis beginning with pre-sorting, followed by cooling down and CA storage of apples.

2.3 Global radiation

Global radiation was chosen as the reference and one of the possible energy sources for fruit storage because global radiation varies with the angle of inclination of the sun and therefore depends on the season and the latitude of the location. With the analysis we focused on the location of Meckenheim/Rhineland, Germany at 50.6°N. We have retrieved the measurement data for all years available (2005-2020) for our location in the European Commission's science and knowledge service with its Photovoltaic Geographical Information System (PVGIS, 2022) which encompasses all wavelengths

(200 - 4000 nm) without overemphasizing any particular wavelength as in the case of PAR (400-700 nm) as the basis for generating photovoltaic energy.

2.4 Photovoltaic energy production

PVGIS was employed to calculate the performance of a 1000 m² grid-connected, mono-crystalline silicone, fixed angle roof-top photovoltaic system with an optimized slope of 35° for our location and a radiation use efficiency of 20% with a nominal power of 200 kWp and a default system loss of 14%.

2.5 Carbon footprint calculation for different energy sources

We assume that the different electricity sources for the storage or cooling system of the apples (grid electricity, solar electricity and heavy fuel oil) have different impacts on the carbon footprint of the product. To calculate these, we used data from the German Federal Environment Agency to calculate the emission factor for the German electricity mix (BMU, 2021) with emissions of 101-111g CO_2-eq/MJ. Due to the difficulty in calculating future policy developments, which envisage long-term fossil fuel reductions for grid electricity generation but do not currently propose a solution to bridge the supply gap, we assume for the calculation that CO2 emissions will decrease by an average of 10% over the next 20 years, as they have in the past. To assess GHG emissions from solar energy, we used the Federal Environment Agency's values of 9.7-15.5 gCO_{2e}/MJ (BMU, 2019). Emissions from solar energy do not occur during operation, but through the production and disposal of the modules. We estimate the values for a PV system made of monocrystalline silicon and an efficiency of 20%. For the calculation of heavy oil emissions, we used data from the German Federal Environment Agency of estimated 79.6 to 81.3 g CO_{2e}/MJ (UBA, 2016) (Table 2). The emissions result from the combustion of heavy fuel oil for ship transport and for energy generation for the reefer containers. The energy demand for the storage of local fruit in the months October to April (181 days) and for the transport and storage of imported fruit from New Zealand (transport distance 23,000 km) is taken from Blanke & Burdick (2005).

Table 2: Values for the carbon footprint calculations

Source	Minimum	Average	Maximum	Unit
CO_{2e} emissions for solar energy	9.7	n.a.	15.5	gCO_{2e}/MJ
CO_{2e} emissions for German grid electricity mix	111.4	n.a.	130.0	gCO_{2e}/MJ
CO_{2e} emissions for heavy oil combustion	79.6	n.a.	81.3	gCO_{2e}/MJ
Energy demand for storage of local fruit	n.a.	977.4	n.a.	MJ/t
Energy demand for transport imported fruit	n.a.	2836	n.a.	MJ/t

2.6 Primary energy analysis

Primary energy values originate from Blanke and Burdick (2005) of 0.81 MJ/ kg apples stored under CA conditions for 7 months (~0.172 MJ/kg/month), thereby contributing approximately 30% to overall energy balance of 5.8 MJ/kg home-grown apples in the Meckenheim fruit growing region of Germany (50.6°N). The pre-cooling can account for a 30-45% increase in energy consumption in the first month, equivalent to 86kJ/kg (Blanke and Burdick, 2005). For the apples from overseas the data regarding the primary energy demands were taken from literature (Blanke and Burdick, 2005).

2.7 Calculation of the profitability of the PV system

The R package decisionSupport (Lüdeling et al. 2021) was used to calculate the net present value (NPV) representing the net financial gain for the decision of the model fruit farm (Table 1) to install and run a 1000m² mono crystalline silicon, fixed angle roof-top PV system with east-west orientation for the time period of 20 years. Data were taken from literature, short expert interviews and PV system cost estimates.

3 Results

3.1 Global radiation at Meckenheim, Rhineland

The fluctuation of the available global radiation during the winter months at Meckenheim, Rhineland (50.6°N) was calculated. Different radiation intensities over the course of the year with the fluctuations over 16 years in the years 2005-2020 as calculated by the PVGIS tool have been identified and quantified.

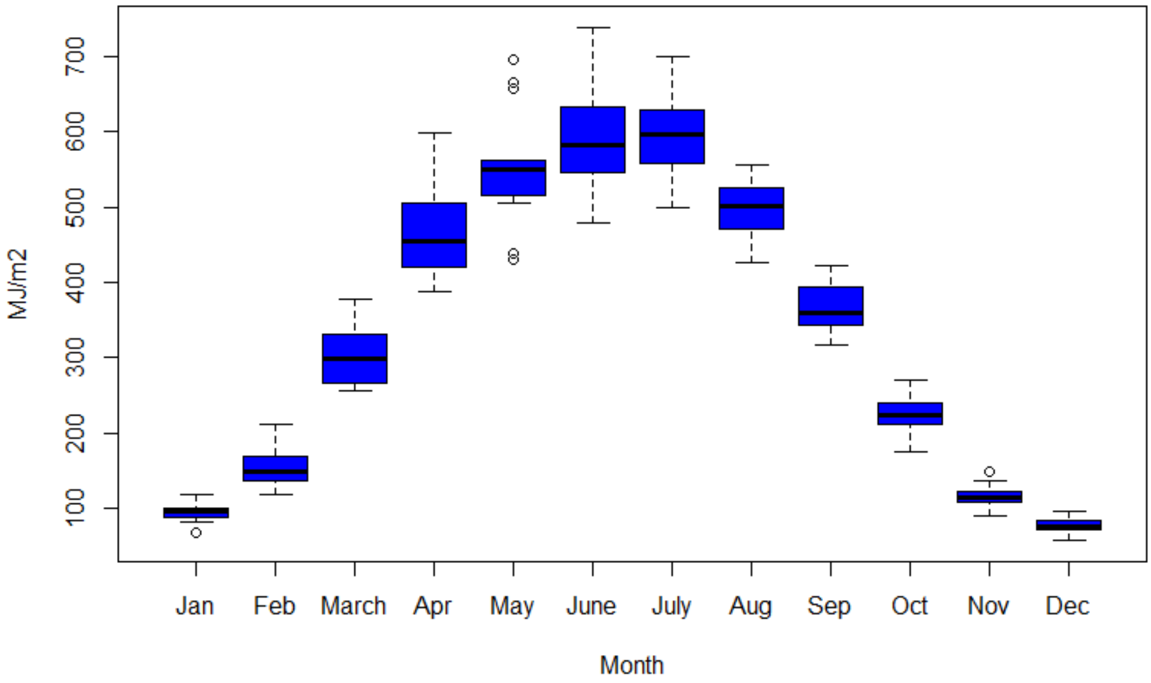

Figure 2: Monthly global radiation (MJ/m²) between 2005 and 2020, computed for 50.6°N, Meckenheim/Rhineland, Germany (Data PVGIS 2022, own visualisation).

3.2 Comparison of energy production and demand

The solar energy generation potential was calculated from the global radiation on a PV system of 1000 m², with a radiation use efficiency of 20% given a fixed angle grid-connected monocrystalline rooftop photovoltaic system with an estimated nominal power of 200 kWp and an estimated system loss of 19.5% due to losses in cables and power inverters as well as due to suboptimal temperature and irradiation. Based on the measurements of the global radiation, the potential energy production per month with a PV system on the roof of the warehouse was calculated (Figure 3).

The values are shown with the double standard deviation added and subtracted from the mean to show the upper and lower boundary for a confidence interval of 95%. The data show a wide distribution of energy values. This means a high level of energy fluctuation and supply uncertainty for the farms which must be compensated for by a power supply via the electricity grid (Figure 3).

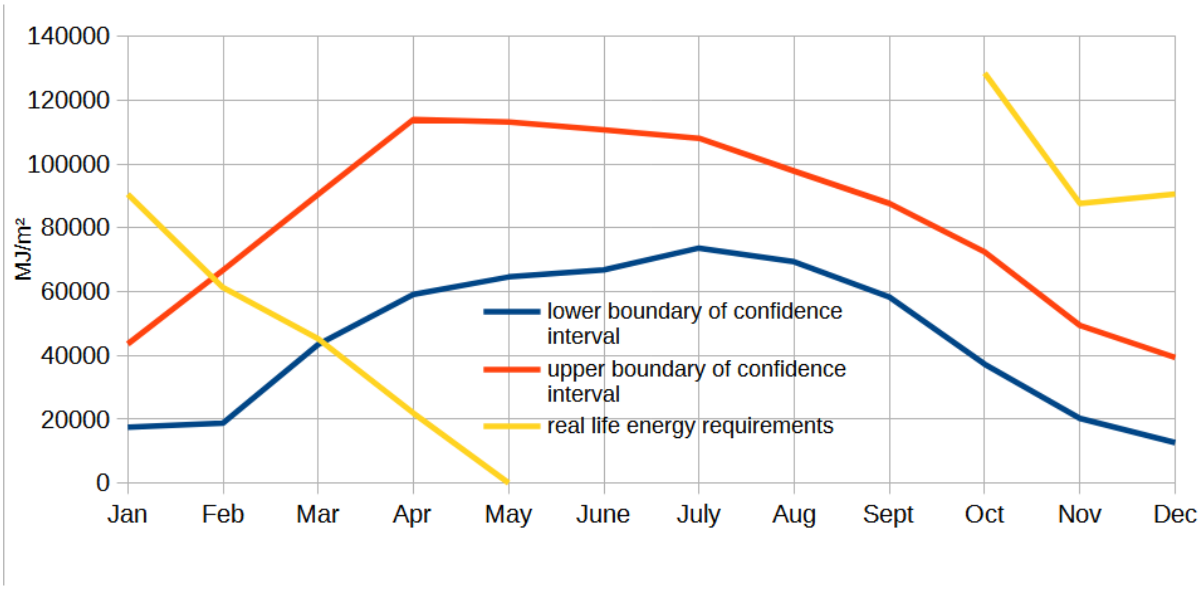

Figure 3: Monthly energy output from a PV system (MJ/m²) with 200kWp in the Rhineland with asynchronicity in solar energy production and theoretic energy requirements for the apple storage facilities. Given is the average monthly energy production (arithmetic mean 2005-2020) + double standard deviation for the upper/ lower boundary of the confidence interval (data PVGIS 2022, own visualization).

Based on the natural solar cycle in the northern hemisphere solar energy production has a plateau in late spring and summer from April to September, decreases then until the minimum in December and increases from the minimum to reach the plateau in April again. The apple storage facilities need the energy at the peak in October for cooling down the entire harvest. For keeping the stored fruit at 1-3°Celsius and under a controlled atmosphere (CA) of 1-3 % CO_2 and 1-3 % O_2, during the months October until April, a constant amount of energy of 0.172 MJ/kg/month apples (Blanke & Burdick, 2005) is needed. From April, domestic supplies begin to run low, and the CA storage rooms are not used until October at the earliest, once the apple harvest is complete. So that between May and October no energy is needed for storage. Global radiation declines from 220 MJ/m² in October to a minimum of 76 MJ/m² in December with a subsequent increase to 469 MJ/m² in April. This is reflected by a decline of energy production from October to December and an increase from December to March (Figure 3). A deficiency of solar energy production during the entire storing period can clearly be noted. The energy required for CA storage of apple fruit peaks during the first month due to the cooling down phase which requires 0.082 MJ/kg apples in the first three days and adds then to the general energy requirement for storage of 0.172 MJ/kg apples (Blanke & Burdick, 2005).

3.3 Carbon footprint

We calculated the carbon footprint for 1 kg of apples depending on the share of energy that was generated by prosumption on the roof of the fruit store on the model farm for storing apples from October to April (Table 3). We compare the carbon footprint of fruit stored in i) a 100% grid electricity powered storage facility, ii) a partially solar powered storage facility from the own roof (1000m² roof/ 200kWp) and iii) a 100% solar powered storage facility and iv) imported fruit from New Zealand. A 100% solar-powered fruit storage system is theoretically possible, but the basic assumptions of our calculation would have to be adjusted. In concrete terms, this would mean increasing the output of the PV system by expanding the area or using electricity storage, e.g. batteries, to bridge under-supply states. These changes and additions are theoretically possible but are not included in the present calculation.

In summary, the carbon footprint is negatively related to the share of solar energy in the total energy demand. The higher the share of solar energy in the total energy demand, the lower the emissions caused by the energy consumption of the storage facilities. The lowest amount of emissions is therefore be caused by the theoretically 100% solar powered storage facility. The total energy demand in winter in Meckenheim cannot be covered 100% by global radiation if only the assumed minimum roof area of the storage hall of 1000m² is available. In this case, the remaining energy demand must be covered by grid electricity. The CO_2 footprint from this mixed procurement of own electricity (solar) and grid electricity (German energy mix) is the option that causes the second least emissions. Apples stored in a storage powered solely by grid energy cause approximately 1.5 to 2 times the amount of emissions compared to the mixed purchase of energy from the sun and the grid energy. However, this option is still more favourable in terms of emissions than imported goods from New Zealand.

Table 3: Range of calculated CO_{2e} emissions per kg apples depending on the origin of the fruit and the energy source for the fruit storage.

Source	Minimum	Maximum	Unit
CO_{2e} emissions for apples stored in a 100% solar energy powered storage	9.5	15.1	gCO_{2e}/kg
CO_{2e} emissions for apples stored in a solar energy powered storage, covering energy gaps with grid energy	24.0	67.4	gCO_{2e}/kg
CO_{2e} emissions for apples stored in a 100% German grid energy mix powered storage	108.9	127.1	gCO_{2e}/kg
CO_{2e} emissions for apples imported from overseas (NZ)	225.7	231.4	gCO_{2e}/kg

3.4 Financial viability

The financial benefit of the decision to install a PV system under given conditions of the model farm in Meckenheim/Rhineland, Germany (50.6°N) and operate it for 20 years was calculated with the R package decisionSupport (Lüdeling et al., 2021) and the values taken from the literature and own calculations (Annex A).

The probability distributions and the outcome for the decision to refuse installing a PV system and the decision to install it as well as the net present value (NPV) of the decision have been compared (Figure 4). Based on our model, the probable NPV of the installation of a PV system has its maximum closely to a financial benefit of about 250000 € over 20 years minus all investment and operating costs. Here, the annual fluctuations in radiation intensity influence the result much less than the future development of the price for grid electricity. For our case, we calculated a moderate electricity price increase of 2% annually over 20 years.

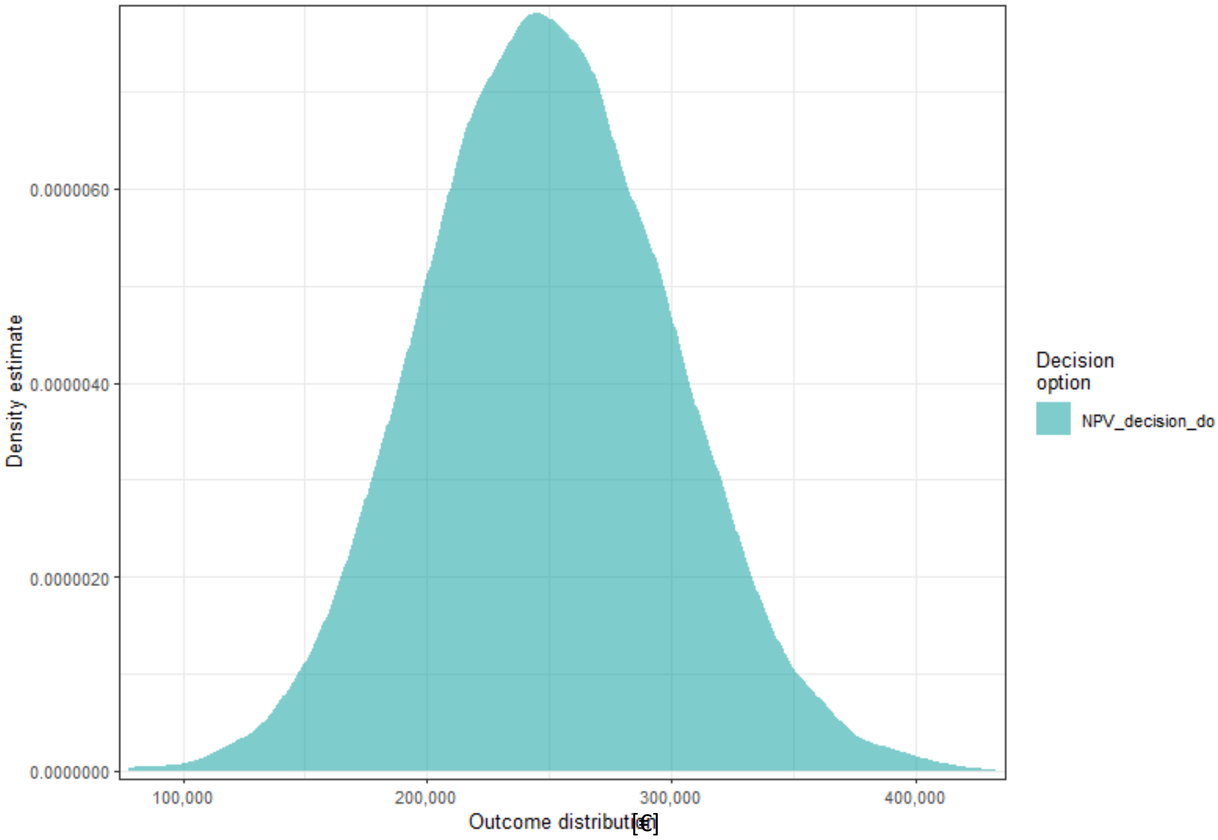

Figure 4: Probabilistic outcome projection for the decision to install a PV system on the rooftop of the model farm. Under the given conditions projected on a time span of 20 years, it can be demonstrated on the basis of the mathematical model that the highest probability is given for a positive result of about 250.000€ for the farm.

4 Discussion

According to our calculations, the fruit value chain can support the energy transition, achieve the goal of a low-carbon fruit supply, and provide additional income to the farm. Our hypothesis was that the use of solar energy for storage facilities can significantly contribute to further improving the overall carbon footprint of regionally grown and locally consumed apples. We found a strong correlation between the carbon footprint and the percentage of solar energy consumed. The higher the percentage of solar energy, the lower the emissions caused by the energy consumption of the warehouses. Our projection shows that 38-81% of carbon emissions can be reduced, so our hypothesis holds true.

Although our calculations are based on data that is 2005, we believe the hypothesis is valid for the following reasons: efficiency gains in refrigeration would be expected in the last 15 years, but there is no published data on this. The reason for this could be that there has been little progress in this regard over the last 15 years. This could be due to generally low energy prices and the lack of a regulatory framework. The experts we interviewed stated that from a technical point of view - if the cooling strategy remains the same in terms of temperature, air circulation, control of gas content, etc. - no major improvements are possible. Only through the farmer's decision to take a higher risk through higher storage temperatures or to invest in the installation of additional fans or sensors would a reduction in energy consumption be possible. The most significant effect could be achieved by increasing the insulation of the cold storage cells. However, this would mean an enormous additional financial burden for the farms. Farmers are therefore essentially guided by the minimum insulation conditions required by law, which have not changed in the last 17 years. We therefore conclude that the 2005 data are still valuable as a basis for calculation.

Whether the reduction potential from energy consumption will remain consistently large in the future depends largely on the design of the German energy mix. The larger the share of renewables and the smaller the share of fossil fuels, the lower the calculated carbon emission savings between own solar power and emissions from grid purchases will be. In the future, we even expect i) more intense global radiation, ii) technological improvements that will lead to better performance of PV systems, and iii) technological advances that will also enable energy savings in fruit storage and storage strategies (East et al., 2013; Neuwald et al., 2015). These developments are very positive and may have a positive impact on the adoption of PV systems and the further reduction of emissions caused by energy consumption on farms.

However, the particular environment of farms should be considered, which affects the implementation options of farms and the installation probability of PV systems. Unlike other economic systems, agricultural production systems are characterized by their strong involvement in and dependence on natural cycles and the resulting high production uncertainty. In our case, we see these uncertainties in the annual variations of available global radiation and in a variation of crop yields. Although many farmers are interested in becoming more sustainable and using sustainable energy sources for fruit storage, they are hesitant due to the uncertainty of if and when the investment will ever pay off. Therefore, the second objective of the present work was to estimate the expected net benefits of using solar panels for a more sustainable production system in horticulture. We used a probabilistic decision analysis approach to estimate the investment risk for farms and to demonstrate the financial viability of the PV system.

Due to certain risks associated with production, storage, and marketing, such as unpredictable weather events like late frost and hail, quality degradation in fruit storage, and fruit price fluctuations, fruit growers need to build financial reserves that are not available for large investments, such as installing a PV system, without creating further risks to the farm. The financial viability of PV systems must be decided on a case-by-case basis. However, our calculations indicate that the installation of a PV system is associated with low risks and large profit opportunities under the selected conditions. In addition, energy prices on the world market are expected to increase, so investing in PV energy may be a profitable option in the future.

Overall, this work has shown that solar panels installed on the roofs of fruit farms are beneficial to both society and the farm. They are able to reduce the emissions caused by the energy consumption of CA storage facilities in winter by 38-81%, thus significantly reducing the carbon footprint of the apple value chain while contributing to the farm's income.

5 Conclusion

Blanke and Burdick (2005) used the primary energy analysis of domestic apples compared to imported apples from overseas to demonstrate that the energy balance was more advantageous until the month of April for the local product. In our analysis, we were able to show that the advantage of the local product can be increased and extended. The key is the source of energy. Where the energy comes from is not irrelevant when we analyse the carbon footprint of the product and the energy costs of the farm. Apples stored in a storage powered by solar energy cause less emissions than apples stored in a storage powered by grid electricity which are still more favourable than apples imported from overseas. In view of the high environmental risks associated with the extraction and combustion of fossil fuels, it is questionable how long society will continue to demand a product that has to be transported over thousands of kilometres on fossil fuel-powered reefers.

Furthermore, the economic analysis revealed a financial advantage for the farms in the Rhineland, although the relationship between production and demand in terms of energy supply seems suboptimal at first glance. We therefore see an enormous benefit for the farms and society and conclude that energy prosumption in the fruit value chain can support the energy transition, provided that the stakeholders concerned receive the right information and make the right decision.

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ANNEX A

Table I: Values for the financial viability calculation

unit	description	lower	upper	distribution
MJ/t	Energy consumption for cooldown	86	121	posnorm
€/m²	cost of building a pv system per area	220	250	posnorm
%	Cost of necessary maintenance of PV system per year per area	0.05	0.08	tnorm_0_1
€/MJ	Costs for energy production per MJ (costs of PV system divided by energy production)	0.024	0.024	const
%	discount rate	0.05	0.05	const
MJ/t/d	Energy required for the storage of 1t apples per day	5.4	5.4	const
MJ/m2	energy production per square meter double SD +/-	59.101884	113.886252	posnorm
MJ/m2	energy production per square meter double SD +/-	69.326352	97.746336	posnorm
MJ/m2	energy production per square meter double SD +/-	12.686472	39.313368	posnorm
MJ/m2	energy production per square meter double SD +/-	18.771912	66.692952	posnorm
MJ/m2	energy production per square meter double SD +/-	17.53074	43.569972	posnorm
MJ/m2	energy production per square meter double SD +/-	73.640952	108.038232	posnorm
MJ/m2	energy production per square meter double SD +/-	66.796956	110.638764	posnorm
MJ/m2	energy production per square meter double SD +/-	43.418664	90.462888	posnorm
MJ/m2	energy production per square meter double SD +/-	64.573092	113.1561	posnorm
MJ/m2	energy production per square meter double SD +/-	20.286288	49.375584	posnorm
MJ/m2	energy production per square meter double SD +/-	37.249668	72.415764	posnorm
MJ/m2	energy production per square meter double SD +/-	58.2966	87.609528	posnorm
kWh/t/m	energy consumption per amount per month in an ca system	15	24	posnorm
€/MJ	energy price per MJ from the grid	0.061	0.072	posnorm
%	decrease of energy production capacity per year	0.02	0.05	tnorm_0_1
% / month	percentage of loss per month during storage in ca system	0.1	0.15	tnorm_0_1
a	Time for projecion	20	20	const
ha	production area model farm	16.9	16.9	const
m2	PV system size model farm	1000	1000	const
€/MJ	Solar revenue; money you get for putting energy into the grid	0.014	0.014	const
g/MJ	CO_2 eq emissions for solar energy	9.7	15.5	posnorm
g/MJ	CO_2 eq emissions for German electricity mix	111.38889	130	posnorm
month	average storage time in ca system	3	8	posnorm
month	average storage time in na system	1	1.5	posnorm
%	desired coefficient of variation in percent	0.05	0.15	tnorm_0_1
%	coefficient of variation in apple harvest	0.05	0.1	tnorm_0_1
t/ha	range of maximum yields	32	32	const