Navigating Complexity: Managing Multi-faceted Changes in India's Transport Sector

Dwarkeshwar Dutt[1]

[1]School of Public Policy, Indian Institute of Technology Delhi, India

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Abstract. In roughly the last two decades, new policy objectives like net-zero, developing industrial competence in emerging green technologies, and reducing fuel import dependence have been added over already existing ones like meeting growing fuel demand and air quality improvement to India's transport sector policy mix. To realize these multiple objectives, several alternative fuels and powertrains (AF&P) are being promoted. However, weaving multiple policy goals in a single coherent vision can create tensions between technological trajectories and pose governance challenges (especially in the short- to medium-term). This study takes a brief stock of the variegated AF&P landscape of India and through wide stakeholder interviews identifies three significant governance challenges. It is argued that addressing these would require shifting from the governance paradigm based on linear management of clearly structured problems towards a more reflexive approach. Based on the principles of reflexive governance and transition management, a reiterative governance framework is proposed.

1. Introduction

Traditionally, energy security objective i.e., fulfilling energy demand cost-effectively has been the fulcrum of national fuel policies. However, over the years, environmental concerns like climate change and air pollution have layered new policy objectives such as emission reduction, net-zero goal, and air quality improvement. Moreover, novel alternative fuels and powertrains (AF&P) are being developed and deployed and therefore, developing industrial competence in these new technologies has also become an important policy goal. In India, for instance, ethanol blending program to reduce oil imports was initiated in 2002 and has lately gathered steam. To address the air pollution issue, the Supreme Court mandated the use of Compressed Natural Gas (CNG) in public transport in Delhi 2002 (Narain et al., 2005). Since then, CNG has become a prominent fuel technology and recently the Government of India (GoI) has begun to promote its greener version - bio-CNG (MoPNG, 2022). In 2010, the GoI launched its first policy program to promote electric vehicles (EVs) (Talwar, 2021). It also came out with a methanol roadmap in 2017 and launched National Hydrogen Mission in 2022. A selective chronology of major policy pronouncements for different AF&P is given in figure 1.

However, weaving these multiple objectives into a coherent policy vision can pose governance challenges as objectives may conflict with each other, particularly in the short- to medium-term. In this study, a brief overview of five important AF&P – EV, ethanol, bio-CNG, green hydrogen, and methanol – is provided in section 3, after introduction (section 1) and method (section 2). The fuel technologies are chosen based on their current or near-term market penetration, sustainability potential, and importance in the government's energy transition plans. Based on semi-structured interviews with a variety of stakeholders, the governance implications of managing this diverse landscape are discussed in section 4, which is followed by the final section 5, conclusion.

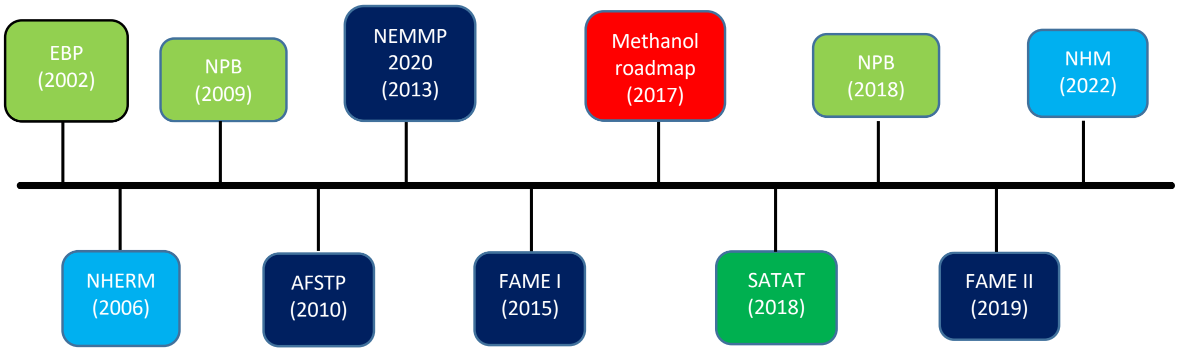

Figure 1. Timeline of major policy announcements (Colour codes for text boxes –electric vehicle: dark blue, ethanol: light green, bio-CNG: green, hydrogen: light blue, and methanol: red)

2. Method

The study employed documentary analysis and semi-structured interviews as methods for understanding India's AF&P landscape and its governance challenges. The documentary analysis consisted of newspaper and magazine articles, think tanks' and consultancy organizations' reports, government reports, and peer-reviewed articles. It provided a useful snapshot of the lay of the land and was supplemented with 21 semi-structured interviews from a variety of institutions such as government ministries, independent think-tanks, government associated organizations, public sector enterprises, and private automotive companies (see Table 1). Stakeholders were identified through a combination of internet search and snowball sampling. The interviews were electronically recorded with the respondents' prior permission.

The interviews were centred on certain themes like broad governance challenges in managing alternative fuels, policy-making processes, government's organizational structure, and conflict between different policy goals. The respondents are given alphanumeric codes like I-1, I-2, etc. to maintain anonymity. The method of thematic analysis was employed to analyse the interview data. Thematic analysis basically involves examining data for prevalence of themes and is a common method for analysing interview or newspaper data (Joffe, 2012). It identifies and enables the researcher to analyse recurring patterns of expressions in her data (Braun and Clarke, 2006). Joffe (2012) argues that thematic analysis is a tool through which both manifest and underlying meaning of the data can be systematically analysed by capturing the nuances people bring to their expressions.

Table 1. List of respondents

S. No.	Position/Designation	Institution/Organization
1.	Director	Ministry of Heavy Industries
2.	Senior manager	Gas Authority of India Limited
3.	Research scholar (energy transition)	Council on Energy, Environment and Water
4.	Sr. deputy director	Automotive Research Association of India
5.	Deputy secretary	Ministry of Petroleum & Natural Gas
6.	Senior manager (project development)	Gas Authority of India Limited
7.	Chief manager	Gas Authority of India Limited
8	Senior Programme Lead	Council on Energy, Environment and Water
9	Distinguished Fellow	Observer Research Foundation
10	Head (Propulsion & Power System)	VegaPod Hyperloop
11.	Designer and technical advisor (automotive sector)	Self-employed
12.	Research analyst (mobility team)	Council on Energy, Environment and Water
13	Senior vice president	Ashok Leyland
14	Senior programme manager	World Resources Institute
15	Energy analyst	Institute for Energy Economics and Financial Analysis
16	Powertrain designer	Daimler Trucks Asia
17.	Manager	Euler Motors
18.	Energy consultant	Deloitte
19.	Senior manager	VOLVO Group India Private Limited
20.	Engineer	Bharat Petroleum Corporation Limited
21.	Senior officer	Gas Authority of India Limited

3. AF&P landscape in India

3.1. Electric vehicles

3.1.1. Policy initiatives and prospects

The first policy program to support EVs in India – Alternate Fuels for Surface Transportation Program (AFSTP) – was launched by the Ministry of New & Renewable Energy (MNRE) in 2010. Under AFSTP, INR 950 million was set aside for the period 2010-2012 for developing and promoting EVs (Talwar, 2021). The policy boosted the market of electric two-wheelers but sales declined sharply when it was terminated in 2012 (see figure 2) (Dutt, 2023; Tryti and Pareek, 2017). After that, the GoI introduced a more comprehensive National Electric Mobility Mission Plan (NEMMP) 2020 in 2013 (NEMMP, 2020). As part of NEMMP 2020, the government launched FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme (see Table 2). The first phase of the scheme lasted from 2015 to 2019 and the second phase begun in 2019 and will last till 2024 (FAME phase-I; FAME phase-II).

Table 2. Allocations under FAME schemes (Parihar and Urele, 2021).

FAME scheme phase-I		FAME scheme phase-II	
Component	Allocated fund (INR billion)	Component	Allocated fund (INR billion)
Technology platform	1.9	Demand incentives	89.56
Demand incentives	49.5	Charging infrastructure	10.00
Charging infrastructure	.30	Administrative expenditure	.38
Pilot projects	.70	Total for phase-II	96.34
IEC/operations	.10	Committed from phase-I	36.6

EV industry is a globally developing industry and a well-functioning self-sufficient EV supply chain would make countries less dependent on others for critical inputs. The GoI also launched National Mission on Transformative Mobility and Battery Storage in 2019 which is a phased manufacturing program to build domestic battery manufacturing capability (Parihar and Urele, 2021). NITI Aayog, a government think-tank, has also initiated National Programme on Advance Chemistry Cell Battery Storage which incentivizes setting up large battery production units with a capacity of at least 5 GWh (Gode et al., 2021). Finally, recent changes in the FAME scheme mandate domestic content requirement for EV producers for promoting domestic EV manufacturing (Dutt, 2023). A report by think-tank, Council on Energy, Environment and Water (CEEW), estimates that a strong policy push can lead to EV sales between 14 and 26 million units by 2030 (Singh et al., 2020).

3.1.2. Current market scenario, projects, and challenges

In India's automotive space, the electrification is expected to happen unevenly. Of the total EV sales, 79% is constituted by electric three-wheelers (including electric rickshaws), 17% by electric-two-wheelers, and merely 4% by electric four-wheelers (Parihar and Urele, 2021). The market for electric two-wheeler segment has expanded because of decreasing battery prices, government's policy push, and entry of vibrant start-ups like Ather (Dutt, 2023). In the high weight vehicle segments i.e., trucks and buses, the electrification is mostly happening at the level of public and private demonstration projects and small-scale pilot projects (PTI, 2022; HT Brand Studio, 2020). In the bus segment, for instance, the number of electric buses in India has increased from near zero in 2017 to more than 4000 in 2022 due to the government's procurement strategy (Wadhwa, 2022).

There are three significant issues pertaining to India's EV transition. First, India has to build a strong EV manufacturing capacity so that it does not lag behind other countries (Behuria, 2020). This would require a strategic policy framework, raw materials availability, and sufficient finance. A report estimates that building manufacturing capacity targeting 50% to 100% localization would need between INR 500 billion and 1 trillion (Singh et al., 2020). Also, the government has to secure supply of critical minerals such as lithium, nickel, graphite, and cobalt to build a complete supply chain and shield India from global fluctuations (Kumar and Thoopal, 2022; Parihar and Urele, 2021). Second, currently India has inadequate charging infrastructure which has to be expanded considerably to alleviate range anxiety of customers. According to an estimate, India would need close to 3,000,000 public charging stations by 2030 to support its EV targets (Gode et al., 2021). Further, due to unique factors like high number of electric two- and three-wheelers, hot and humid environment, and poor quality of grid electricity, India would need its own context specific solutions and can't adopt other countries' strategies (Lakshmi, 2022). Third, India's current EV penetration is very low and thus the market has to grow substantially to support its domestic manufacturing ambitions and encourage entry of new players. For this, India needs to adopt stronger EV policies along the lines of EV mandates adopted by California and China (Roychowdhury et al., N.D). Lack of clear policies also result in unwillingness of financial institutions to involve in extending debt to EVs and thus stifle the market (Singh et al., 2020).

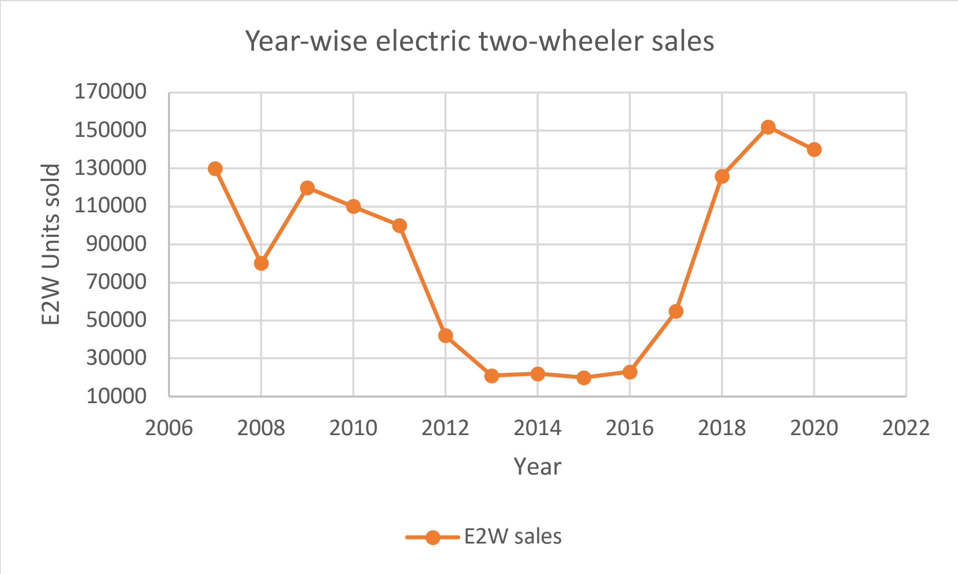

Figure 2. Electric two-wheeler sales in India. Source: Dutt (2023)

3.2. Ethanol

3.2.1. Policy initiatives and prospects

The initiatives to promote biofuels like ethanol began from early 2000's because of the rising oil imports (Saravanan et al., 2018). In 2001, a small 5% ethanol blending pilot programme was started, which was followed by India's first large scale ethanol initiative – Ethanol Blending Programme (EBP) – by the Ministry of Petroleum and Natural Gas (MoPNG) in 2002. It mandated 5% ethanol blending from 2003 in certain states and union territories (Aradhey, 2010). In 2009, National Policy on Biofuels (NPB, 2009) was adopted, which abandoned the mandatory aspect and adopted a target of 20% ethanol blending by 2017 (Chandel et al., 2017). In 2018, in the next iteration of biofuel policy – National Policy on Biofuel (NPB) 2018 – a target of 20% ethanol blending with petrol by 2030 was adopted (Das, 2020). Unlike earlier ethanol policies, NPB 2018 adopts a more holistic perspective and in addition to reducing oil import dependence, also focuses on augmenting farmers' income, generating rural employment, and promoting sustainability through judicious use of drylands (Prasad et al., 2020). It also provides a strong push to 2G ethanol that is produced from waste and doesn't conflict with food security. It adopts a Viability Gap Funding (VGF) scheme for infrastructure development under which a financial aid of INR 50 billion has been allocated for setting up of 2G bio refineries (CCEA, 2019). However, NPB 2018 also allows ethanol production from edible feedstock like sugarcane juice, sugar beet, sweet sorghum, and starch containing materials like corn (Mookherjee, 2022). Estimates show that 10% ethanol blending that India achieved recently has enabled it to save INR 410 million worth of fuel imports (Livemint, 2022).

India produces enormous quantities of agricultural waste which can be used for producing 2G ethanol. If such ethanol plants are set up, numerous rural job opportunities can be created in the areas of baling, hauling, transportation of biomass, and operation of plants (Singh et al., 2017).

3.2.2. Current market scenario, projects, and challenges

Most of the ethanol produced in India is utilized for the production of potable liquor and the surplus is used for fuel blending by Oil Marketing Companies (OMC) (Dey et al., 2023). In the last 5-6 years, India's ethanol production capacity has increased considerably (see figure 3). For instance, between 2010 and 2019, a 3700% increase in ethanol production for blending purposes has been seen (Roy et al., 2019). Recent estimates show that ethanol production capacity in India stands at around 9 billion litres of which 84% of ethanol is derived from sugarcane, 10% is accounted for by Food Corporation of India's rice stocks, and 5 per cent from maize/damaged food grains (Saini et al., 2023). Thus, most of the ethanol produced in India is 1G as more sustainable 2G technology is relatively underdeveloped. To develop 2G ethanol technology, the GoI has provided financial support for the period 2018–19 to 2023–24 for setting up of 12 commercial scale and 10 demonstration scale 2G ethanol projects using lignocellulosic biomass and other renewable feedstocks (Roy et al., 2019).

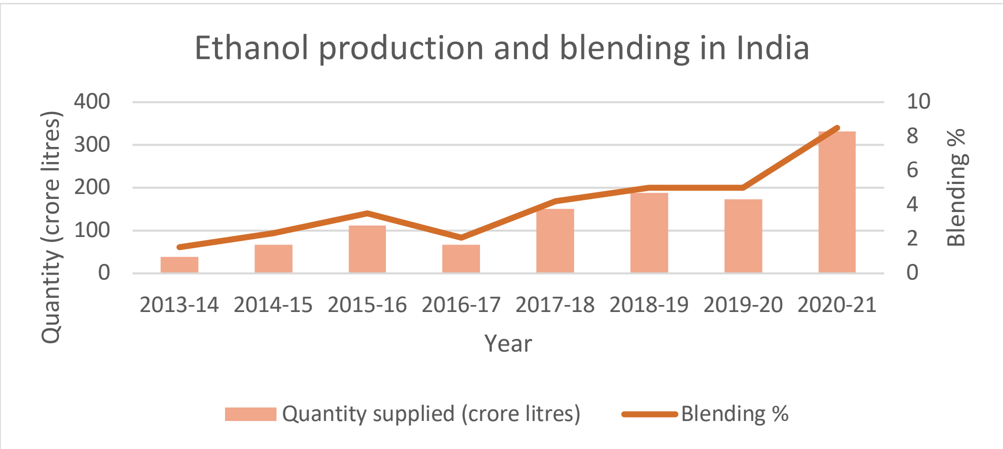

Figure 3. Ethanol production and blending in India (Source: MoPNG, 2022) (1 crore = 10 million)

The ethanol production in India faces several challenges. For 2G technology, the procurement window for agricultural waste feedstock is 15-20 days which makes it difficult to establish a sustainable biomass supply chain (Pandey et al., 2021). Sugarcane crop, which is a significant source of ethanol feedstock in India, is a very water intensive crop. One litre of ethanol from sugarcane requires about 3,000 litres of water. As India attempts to increase its ethanol production, groundwater depletion may get worse (Lee et al., 2020). Completion of all the stages of sugarcane cultivation takes a long time rendering the land useless for cultivating other crops for about 4-6 years (Seth et al., 2021). Thus, increasing ethanol production may also interfere with India's food security.

3.3. Bio-CNG or compressed biogas (CBG)

3.3.1. Policy initiatives and prospects

CNG was introduced in India in early 2000's to improve air quality and has become an important part of the government's pollution control strategy since then (Bell et al., 2005). Further, the government wants to increase the share of gas in its energy mix from current 6.2% to 15% by 2030 (Nouni et al., 2021). A big part of this increase is expected to come from CNG deployment. However, increasing CNG production would adversely affect India's energy security as India imports around 50% of its natural gas. Further, although CNG produces less emissions than gasoline and diesel but it is still a fossil fuel. Bio-CNG on the other hand more sustainable than CNG as it is produced from agricultural, cattle, and urban wastes and can easily replace CNG (Munagala et al., 2022; Singhal et al., 2017).

The bio-CNG potential in India is estimated at 62 million metric tonnes (MMT). Therefore, the government launched the SATAT (Sustainable Alternative Towards Affordable Transportation) scheme in October 2018 to promote bio-CNG. SATAT policy plans to invest INR 2 trillion to set up 5000 bio-CNG plants across the country. This would result in production of 15 MMT of bio-CNG and 50 MMT of bio-manure as a by-product. Under the scheme, several incentives are provided such as assured offtake of the bio-CNG produced, long term agreements, priority sector lending, and financial assistance depending on the volume of bio-CNG produced with a cap of INR 100 million (MNRE, 2022).

3.3.2. Current market scenario, projects, and challenges

There are currently 17 bio-CNG plants operating in the country having an aggregate production capacity of 46,178 kg/day. Most of them are located in the western and northern parts of the country (Goyal, 2018). Governments trying to find a solution to the problem of rising waste are exploring bio-CNG plants as an option. For instance, Delhi government recently announced that it will set up 3 new biogas plants (Manupriya, 2018). India also has Asia's largest bio-CNG plant in the Sangrur district of the Punjab state and following setting up of this plant, the Punjab government is planning to set up 42 more plants that would cumulatively produce 492.58 tonnes of bio-CNG per day (Gulati, 2022, Kumar, 2022). It has also been reported that influential industrial houses such as Reliance Industries and Adani New Industries Limited are planning to make considerable investments in setting up of bio-CNG plants (Pathak, 2022).

A key challenge in the development of bio-CNG (and CNG as well) is the lack of pipeline infrastructure. Gas pipeline infrastructure is regionally skewed and its uniform expansion is necessary to boost demand (Corbeau et al., 2018). Also, the bio-CNG supply chain comprises different sectors like agriculture and urban waste and their co-ordination presents difficulties in efficient supply chain management. For instance, there is a lack of aggregation yards and formal aggregation models for collecting agricultural and livestock waste (Shrivastava, 2022). Similarly, many cities don't have adequate waste segregation facilities which are needed for bio-CNG plants' operation (Narayana, 2009).

3.4. Hydrogen

3.4.1. Policy initiatives and prospects

MNRE brought out India's first hydrogen and fuel cell roadmap called National Hydrogen Energy Roadmap (NHERM) in 2006 (Gupta et al., 2022). However, there has been a recent surge in the global attention to hydrogen. Therefore, the GoI launched a more holistic hydrogen initiative – National Hydrogen Mission – in 2022. The mission focuses on developing complete hydrogen value chain, catalyzing demonstration programs, development and deployment of hydrogen technologies, and addressing concerns pertaining to safety and standards (Qureshi et al., 2022). A national body called Indian National Hydrogen Energy Road Map (INHERM) has also been set up to promote hydrogen utilization in the power and automotive sectors (Greig and Sharma, 2022). The government has also launched an ambitious 'hydrogen 2-1-2' initiative which aims to decrease the cost of hydrogen fuel by two times compared to gasoline, reducing the cost of hydrogen storage, distribution, and refuelling to less than $1, and generate a favourable return on investment for hydrogen in less than two years (Kannah et al, 2021). India already is one of the cheapest producers of solar energy which can be leveraged to power production of green hydrogen (Bhardwaj, 2021). Green Hydrogen would help India in achieving its goals of energy independence by 2047 and net-zero by 2070.

3.4.2. Current market scenario, projects, and challenges

Hydrogen fuel is currently in the demonstration stage but can find commercial applications in the future in the heavy-duty vehicle segment where electrification is less feasible (Danielis, 2020). Several pilot projects have been initiated for testing hydrogen fuel's feasibility. Tata Motors in collaboration with Indian Oil Corporation Limited and Indian Space Research Organisation (ISRO) showcased India's first hydrogen fuel cell bus in 2018 (Express drives desk, 2018) and after evaluation of the trial run, Indian Oil Corporation Limited invited bids for 15 fuel cell buses in 2020 which was won by Tata Motors. The buses are expected to be on road in June 2024 (Anon. (2021). Two hydrogen refuelling stations have also been set up at Gurugram and Faridabad in the state of

Haryana by Indian Oil R&D Centre and National Institute of Solar Energy respectively (Sontakke and Jaju, 2021). Being a new and undeveloped technology, cost is the most significant barrier for hydrogen fuel. Green hydrogen production uses water electrolysis to produce hydrogen which is a very expensive process and until cost is considerably reduced, hydrogen take-off is unlikely to happen. In addition to the cost, other factors like lack of hydrogen fuelling infrastructure, safety concerns, and delicate powertrain system of hydrogen vehicles also inhibits its uptake (Das, 2021).

3.5. Methanol

3.5.1. Policy initiatives and prospects

Methanol, also known as wood alcohol, is an alternative biofuel that can be blended with gasoline and used in ICE vehicles. It can be produced from a variety of sources like natural gas, coal, and biomass (Saraswat and Bansal, 2021). It is a recent addition to the AF&P basket in India and as such planning is still in the early stages with no clear policy roadmap. However, some recent high-level initiatives regarding methanol fuel development indicates the government's seriousness in developing it.

In 2016, NITI Aayog organized an international conference on methanol economy to elicit perspectives from various stakeholders like industry, academia, policy makers, and government officials (Shih et al., 2018). Following this, a taskforce called Methanol Economy taskforce was set up which published a report in 2017 with the title 'India's Leapfrog to Methanol Economy'. The report highlighted methanol's potential in reducing oil and gas imports and argued for increasing use of methanol as transportation fuel, cooking fuel, and as a diesel substitute in power generators used in telecom towers (Saraswat and Bansal, N.D).

In December 2017, NITI Aayog announced that it is preparing a roadmap for India's methanol economy and proposed a plan to set up a Methanol Economy Fund of around INR 50 billion (Saraswat and Bansal, 2021). An important benefit of using methanol as an alternative fuel is that since it can be produced from coal gasification, it can allow for optimum usage of India's coal reserves. Coal usage for power generation is likely to decline in the future and India can divert its vast coal reserves for methanol generation. Moreover, coal gasification when combined with CCS technology produces very little emission and therefore can contribute to India's net-zero goal (Shih et al., 2018).

3.5.2. Current market scenario, projects, and challenges

India has very low methanol production capacity. In 2020-21, its methanol production capacity was 0.23 million tonnes (Mt) (Saraswat and Bansal, N.D). In contrast, China blended around 21 Mt of methanol with gasoline in 2016 (Anon., 2023). At present, there are no commercial scale methanol plants in India but the government has set up some pilot projects. A technology demonstration public-private partnership project has been initiated between a prominent Indian technological university and Thermax, an environmental solutions company. The aim of the project is to develop and refine indigenous technology for methanol production from high-ash Indian coal (Anon., 2020).

A pilot project to study the feasibility of 15% methanol blended petrol (M15) has been started in the state of Assam and would be extended to other areas if the outcomes are satisfactory (Ray et al., 2021). The main challenge in developing methanol fuel in India is lack of a clear policy roadmap or mission. Some visions and goals have been stated but a detailed roadmap is yet to be articulated by the government. Another obstacle is uncertainty regarding production cost. While Saraswat and Bansal (2021) argue that methanol would be cheaper than ethanol and petrol even when subjected to comparable tax regimes and other costs, however, in absence of commercial scale production, an accurate picture can’t be provided.

4. Discussion

4.1. Governance challenges

The energy transition in India’s transport sector is currently in a state of great flux. The government is trying to achieve multiple objectives and aggressively promoting many AF&P that are at different stages of maturity (see Table 3 for summary). The progress on ethanol blending and EV penetration is taking place gradually, though the ambitious targets are likely to be missed. Bio-CNG has the advantage of a ready market but has not taken off as expected. Methanol and green hydrogen are at very early stages of development and would require sustained support for years to mature as viable fuels.

Ethanol and methanol blending will help in reducing oil imports and save foreign exchange, bio-CNG deployment can be very effective in reducing vehicular air pollution in cities and reduce gas imports to some extent, and EVs and green hydrogen fuel are expected to support long term net-zero and industrial development goals. Different technological options, thus, are underpinned and justified, to different degrees, by different values such as long-term environmental sustainability, industrial competence, energy security etc. and currently all desirable values don’t converge into any single option (see Table 4). These different objectives are likely to be achieved at different time scales, require different technologies, different kind of policy support, massive investments and may compete for resources.

Table 3. Summary table for different AF&P

Fuel/Technology	Policy goals and visions	Market status	Main objective(s)	Challenges	Magnitude of Investment
EV	Sales target of 30% for private cars, 70% for commercial vehicles, and 80% for two-and three-wheelers by 2030	Subsidy driven Little market penetration in two- and three-wheelers Procurement driven uptake in public sector city buses Pilot projects in other vehicle segments	Developing industrial competence in EV Net-zero goal	Lack of battery manufacturing capacity Challenges of grid integration Upfront cost of EVs	INR 148 trillion by 2030 to achieve policy targets
Bio-CNG	SATAT scheme envisages 5000 CBG plants with production capacity of 15 MMT of CBG and 50 MMT of bio-manure per annum by 2023-24	Ready market as a percentage of three-wheelers, buses, and cars run on natural gas Slow progress of SATAT scheme with only 38 commissioned plants	Cutting natural gas import dependence Addressing poor city air quality	Supply chain management issues pertaining to aggregating and segregating waste Lack of uptake of bio-manure Shortage of skilled professionals and lack of standards for the waste-to-energy segment Lack of inter-departmental co-ordination	INR 2 trillion to set up 5000 bio-CNG plants by 2024
Ethanol	Blending target of 20% by 2025	Blending target of 9.45% achieved recently Most bioethanol produced through 1g and 2g technology relatively underdeveloped	Cutting down oil imports	Sugarcane farming for bioethanol production leads to groundwater depletion Using food grains can lead to food vs. fuel dilemma Lack of inter-departmental co-ordination	INR 454 billion to achieve 20% blending by 2025
Green Hydrogen	National Green Hydrogen Mission envisages production of 5 MMT of green hydrogen per annum by 2030	Limited to pilot projects for buses and trucks	Developing industrial competence in green hydrogen Net-zero goal	Production processes still expensive Hydrogen production from coal is an emission intensive	INR 197.44 billion approved for National Green Hydrogen Mission
Methanol	No specific targets	Limited to few blending pilot projects	Cutting down oil imports	Nascent technology so considerable ambiguities regarding cost and regulatory structure	Methanol Economy Fund of around INR 50 billion is planned

Table 4. Matrix table of AF&P against policy objectives

	Objectives (Values)	Reducing import dependence (energy security)	Industrial competence	Air quality (short-term sustainability)	Net-zero (long-term sustainability)
Alternative fuel or powertrain					
Electric vehicles		*	***	*	***
Ethanol		***		***	
Bio-CNG		***		***	*
Hydrogen		*	***		***
Methanol		***			

4.1.1. Inter-sectoral co-ordination

A primary challenge in managing simultaneous transitions involving multiple technologies is to forge a strong inter-sectoral co-ordination, which has to be realized at two levels – systemic level and technology supply chain level. At the systemic level, there is a need to co-ordinate the visions and transition trajectories of different fuel options. The governance structure of the fuel options considered in the study is dispersed among different ministries and departments. Therefore, individualistic visions and goals of these organizations have to be woven into a coherent, long-term, unified, and strategic vision. In general, climate policy governance processes in India have been considered as fragmented and lacking a clear vision (Kumar and Naik, 2019). Similar shortcoming was also observed during the interviews with respect to the energy transition governance. A respondent from a public sector enterprise stated:

We [different ministries and departments] apparently have different objectives and aims which can sometimes seem to be not in tune….better co-ordination will surely help in making good policies….hmm….but it's not easy' (I-4)

Another public sector enterprise respondent, I-12, recalled attending an energy conference attended by officials from different ministries and observing 'a general sense of confusion with respect to long-term goals'. Currently, there doesn't seem to be an effective platform where different stakeholders can come together to share their visions and discuss issues regarding the transport sector's energy transition. On being asked if such a platform exists or is currently being planned, a high-ranking ministry official succinctly pointed out that s/he was not aware of any such platform (I-8).

At the level of individual options too, co-ordination between different ministries and departments is needed to establish a robust a supply chain. The supply chain of fuel technologies considered in the study span across different sectors with different organizational and institutional structures. Markard (2018) argues that in the next phase of energy transitions, where focus would be on accelerated deployment, such cross-sectoral linkages would be crucial. For instance, for bio-CNG and ethanol, co-ordination is needed between agriculture, urban waste-management, fuel production, and transport sectors. Similarly, for EVs, co-ordination with electricity sector is imperative for large scale deployment. Respondent I-3, who has been involved in managing ethanol supply chain, stated:

'It is a challenge to maintain biofuel supply chain. There is such a diversity of actors….farmers, biomass aggregators, fuel producers and fuel buyers. Different domains are involved [in the supply chain] and you need people who can bind these domains together'.

4.1.2. Balancing policy neutrality and specificity

In multiple technology options, the question of technology neutral vs. technology specific policy support often arises. Conventionally, popular opinion usually favours a technology neutral hands-off approach, by offering a level playing field with minimum common technological standards and allowing the market factors to play dominant role (Sandén, and Hillman, 2021). This approach is based on the argument that the state is often not in a good position to pick winners (Sandén and Azar, 2005). The automobile lobby organization Society of Indian Automobile Manufacturers (SIAM) has also advised the Indian government to adopt a technology neutral approach (SIAM, 2019). However, some scholars argue that in the context of sustainability transitions, the role of the state should not be limited to providing passive support but rather adopting a more proactive approach (Sandén and Azar, 2005). According to them, sustainability transition is an inherently political process and a hands-off approach may result in sub-optimal outcomes (Azar and Sandén, 2011).

Although by and large, the respondents understood and even accepted the government's obligation to simultaneously promote several fuel options enthusiastically, still, some of them indicated a lack of strategic long-term vision in the current approach. As one think-tank respondent commented:

'It seems that the government's strategy is to throw everything at the wall and see what sticks….they [policy makers] have their reasons for doing so....i know….but a more detailed and strategic approach is required' (I-6).

A respondent from a prominent automobile company also shared a similar sentiment:

'More clarity from the government on the technology direction would be welcome….surely.…but we don't know when we would get it….so, what we are doing is that we are working on multiple technologies so regardless of where markets or government goes….we would be ready (I-11).

A strategic approach going beyond simultaneous promotion doesn't mean picking winners or promoting some selected technologies but aligning the different technological trajectories in a coherent fashion with respect to the long-term sustainability goal.

4.1.3. Articulating the role of gas in the transition

A concrete case of the above ambiguity involves articulating the role of gas in transport sector's energy transition, which was pointed out as a prominent issue by several respondents. A recent official document of the GoI - Long-Term Low Emission Development Strategy identifies gas as a 'transition fuel', however the strategy of employing it as a transition fuel is not clear. Lobby organizations like SIAM and other gas supporters want more incentives for promoting gas deployment and are wary of the government's aggressive EV push (SIAM, 2019). However, as the government expands gas infrastructure with the massive investments, the fear of sunk investments is likely to aggravate concerns over institutional and infrastructural lock-in into gas.

Unfortunately, there has been very little discussion in India's low-carbon transport policy discourse on the possibility of gas lock-in, its implications for India's energy transition, and ways to address it. A report by a think tank, CEEW, did highlight gas lock-in and argued for capping gas penetration in India's energy mix at 18% (Malyan et al., 2021). However, lock-in by its very nature resists such an easy escape at a specified point. A think-tank respondent did recognize the problem as a 'tricky one' but also mentioned that 'the government should be more concerned about meeting India's growing demand' (I-13). On the other hand, a ministry respondent relatively openly acknowledged the governments' ambiguity regarding gas' role:

Yes…it [gas' role] is something we have still not figured out completely….specifically, the CNG vs. electric is a bit of a problematic area for us as of now (I-2)

4.2. Governance paradigm for India's low-carbon transport transition

The traditional governance paradigms were formulated and developed for contexts where problems are clear and structured and policy process is a linear exercise. However, this paradigm falls short in a situation which involves long-term objectives, uncertainties, and potential value conflicts. The governance challenges engendered by such situations are inherently political. Therefore, addressing them would need a governance paradigm suited for long-term policy making, underpinned by consultation and reflexivity.

A significant aspect of this governance paradigm is to understand the interlinkages between technology, values, and policy objectives. Energy technologies are underpinned by different values like affordability, sustainability, industrial competence, feasibility, and efficiency. Among these, the values of sustainability and industrial competence have acquired a prominent place in the energy policy discourse in the last few years. A given technological option may help in realizing some objectives but not others and thus, while promoting a technology, clash between different values (and objectives) is not uncommon (Milchram et al., 2019). However, the connection between values, visions, and technologies in energy systems is often not scrutinized adequately (Trutnevyte, 2014).

According to Busch et al. (2014) a low-carbon strategic vision is constituted by strategic objectives, which are a combination of environmental and economic goals and a strategic framework, which articulates problem framing, desired solutions, and governance processes. Aligning economic and environmental goals is a daunting task and thus the vision has to be developed through an extensive stakeholder consultation. The process is likely to involve negotiations and compromise. In other words, the vision would be political in nature (Azar and Sandén, 2011). Understanding the connection between technology, values, and policy objectives would shed light on the conflicts and complementarities between different visions. Considering the political nature of consultation, identifying these conflicts and complementarities is not likely to eliminate former completely but it can help provide points of deliberation for developing a shared transition vision through wide stakeholder consultation.

During the course of long-term transition, social, political, and economic contexts change. Also, as technologies develop, the complementarities and trade-offs between them are also likely to change. All this would cause a concurrent shift in the dynamics between technology, values, and objectives. Thus, in a rapidly evolving state, any shared vision arrived at has to be periodically revisited and recalibrated. This would require incorporating reflexivity in the governance. In essence, this would require embracing the multi-dimensionality of problem framings and keeping the policy processes and goals open ended. Instead of providing one right solution to the problem, policy making in this case must be a reiterative exercise of experimentation, learning, and knowledge integration (Voß and Bornemann, 2011) (see figure 4).

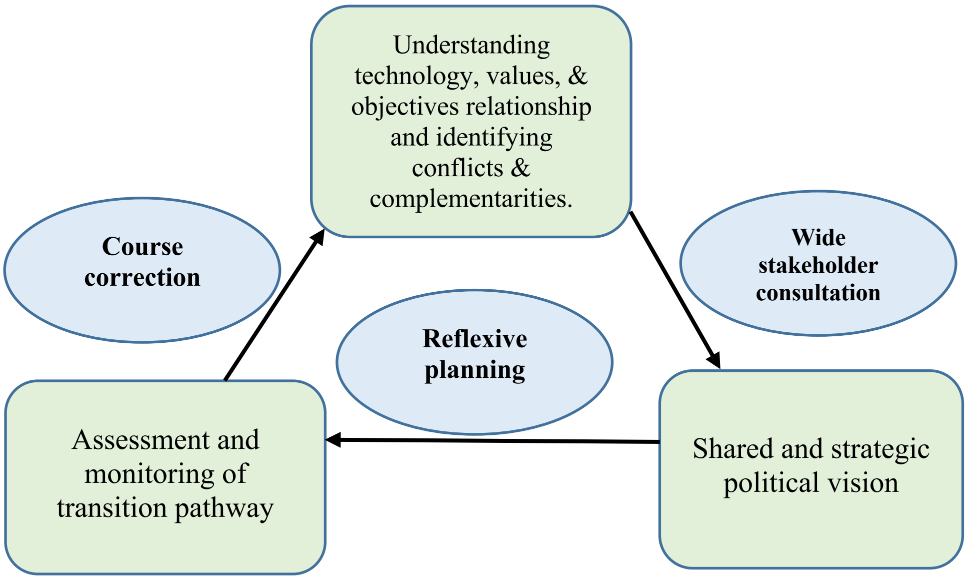

Figure 4. Iterative governance paradigm for development of India's low-carbon transport

5. Conclusion

India's alternative fuels landscape has undergone substantial changes in the last two decades. From being dominated predominantly by a single fuel (gasoline/diesel), it looks much more variegated as the government simultaneously pushes for multiple options to realize its different objectives. This simultaneous development of multiple fuels poses some significant governance challenges that can't be addressed through conventional linear policy making. In this study, we highlighted the governance challenges associated with promotion of multiple technologies at the same time and suggested an iterative governance approach based on the principles of reflexive governance and transition management as an alternative. The approach consists of understanding the sources of conflicts between different objectives, develop a shared vision through wide stakeholder consultation, and periodically calibrating the vision in the wake of changing external conditions.

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