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Barriers to and Opportunities for Light-Duty Vehicle Electrification in India: Insights From a Survey of Experts

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Key Points

The Indian government is considering deploying plug-in electric vehicles (PEVs) in the light-duty vehicle (LDV) sector. This strategy is intended to help meet the country's air pollution, energy security and climate change goals. PEV development is also part of India's industrial policy, as the government aspires to make India a global PEV manufacturing hub. This study therefore investigates the potential for PEV adoption in India, the challenges in meeting the country's goals and ways to overcome these challenges. We utilize a survey of 51 experts in the Indian LDV ecosystem to address these questions. Our results suggest the following:

> The majority of the surveyed experts indicate that India will not meet its 30% PEV sales target by 2030. The main reasons cited for the risk of missing this target are PEVs' high upfront cost, a lack of policies promoting PEVs and a lack of charging infrastructure.

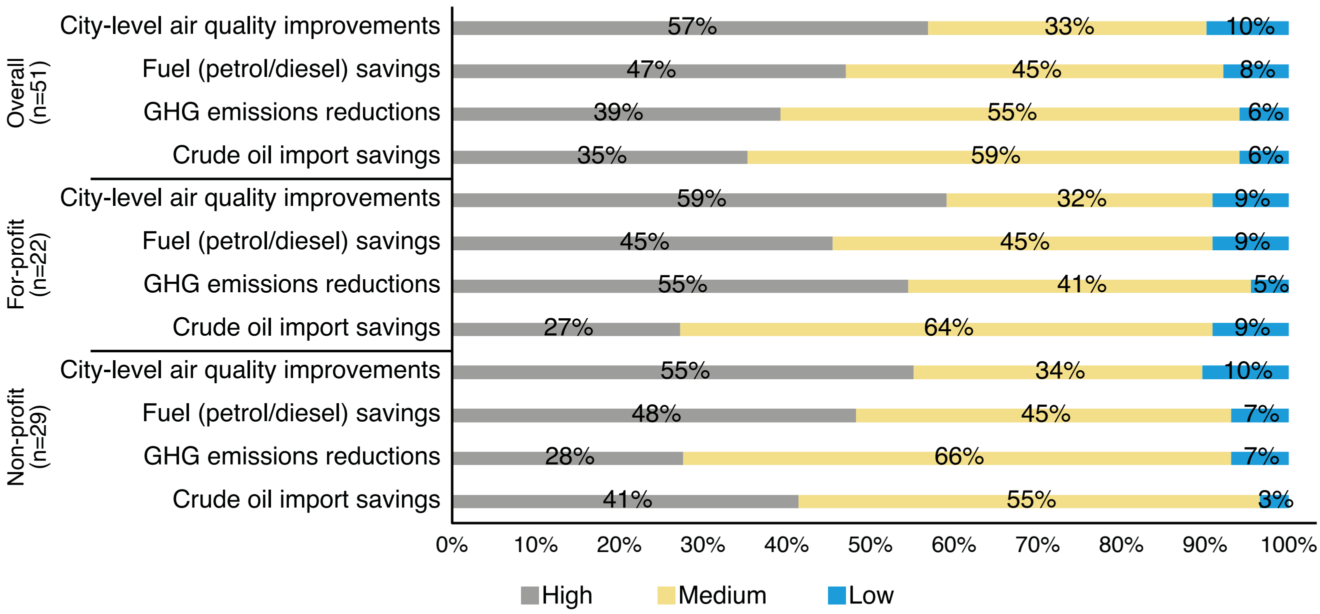
> The experts believe that the lack of PEV battery and manufacturing supply chains will limit the supply of low-cost PEVs to the Indian market.

> The costs of infrastructure equipment and installation, land and electricity are cited as barriers to the establishment of charging infrastructure.

> The experts view a PEV sales mandate and incentives, such as 'feebates,' as the most effective policies for encouraging the PEV market's development in India.

Overall, the findings can help understand the future of India's LDV sector and the associated energy and environmental impacts, which have global implications.

Graphical abstract: Extent of the expected societal gains from India achieving 30% annual PEV sales by 2030.



Source: KAPSARC analysis.

Note: GHG= greenhouse gas.

1. Introduction

According to the World Health Organization, India has the world's worst air quality (Bernard and Kazmin 2018; Parkin 2019; BBC News 2019). Among other factors,[1] vehicular pollution from the increasing stock of passenger vehicles has contributed to India's deteriorating air quality (Bernard and Kazmin 2018). This increasing stock is also a factor in India becoming the third-highest oil-consuming[2] and greenhouse gas (GHG)-emitting country worldwide (Friedrich, Ge, and Pickens 2017; EIA 2019).

To address these issues, in 2017, the Indian transport ministry envisaged a complete transition of newly sold vehicles from gasoline- and diesel-powered to plug-in electric vehicles (PEVs) by 2030 (Plötz et al. 2019; BBC News 2019). In addition, the Indian government set a goal to transform India into a global hub for electric vehicle manufacturing (Ghosh 2019). By 2019, however, the government had adjusted this aspirational target to achieving a 30% market share for PEVs by 2030 (BBC News 2019). Media reports cited industry pushback and the fear of job losses as reasons for lowering this target (BBC News 2019).

PEVs are clearly an important part of India's environmental, energy and industrial policies. However, the challenges faced by the Indian PEV market and the ways to address them are less well understood. This study therefore aims to identify both the important barriers in this market and policy levers for overcoming them. To do so, we examine the Indian PEV ecosystem from both supply and demand perspectives. This study also qualitatively investigates India's expected level of PEV adoption by 2030 and the associated societal impacts.

Based on a review of the literature on PEV adoption in various markets throughout the world, we identify the following research questions for detailed investigation:

- What factors influence consumers' adoption of PEVs in India?
- What factors influence the manufacturing of PEVs and PEV batteries in India?
- What are the barriers to establishing a public charging infrastructure in India?
- What policy levers can help India meet its aspirational target of a 30% share of new sales for PEVs by 2030?
- What societal gains can be achieved if India meets its aspirational PEV target?
- What measures are currently being taken by the Indian central and state governments, and how do they fit with the identified enablers and disablers?

Existing studies in this field primarily focus on North America, Europe and China. Thus, this study differs from prior work because it identifies specific factors that impede the development of a PEV market in India. Additionally, the study contributes to the literature by surveying experts associated with various aspects of the Indian light-duty vehicle (LDV) ecosystem. Thus, our results provide a better understanding of experts' beliefs regarding the future of the Indian LDV sector and the associated energy and environmental impacts.

The rest of this paper is organized as follows. Section 2 reviews other researchers' findings regarding the creation of PEV ecosystems in other parts of the world. This section also highlights previous findings that form the basis for the various themes explored in the survey. Section 3 lays out the roadmap for carrying out the research. We describe the identification of the study population, the formulation of the survey outline and our analysis of the collected survey data. Section 4 presents the findings of our statistical analyses of the survey data based on the themes explored in the survey. Section 5 discusses the analytical findings and highlights the latest policy developments in the Indian PEV ecosystem. It also provides estimates of the expected GHG emissions reduction relative to the business-as-usual case if India achieves its aspirational PEV target. Section 6 highlights key findings regarding the development of the PEV ecosystem. We note which findings are common to India and the rest of the world and which are unique to India.

2. Literature Review

Most prior studies on PEV ecosystem development focus on North America, Europe or China. In this section, we review that literature. We particularly note their insights on challenges and opportunities in introducing electric vehicles, as these insights may be relevant for the Indian market. This literature review also informs our methods, and the results are used to develop the survey themes. Table 1 provides an overview of the literature that informs this study.

Many studies focus on barriers to consumers' purchases of PEVs. One major driver of such barriers is the differences between PEVs and internal combustion engine vehicles (ICEVs). For example, studies typically find that PEVs' low driving ranges are a substantial barrier to their adoption (Carley, Siddiki, and Nicholson-Crotty 2019; Schneidereit et al. 2015; Franke et al. 2012). This barrier is exacerbated by long battery recharging times (Berkeley, Jarvis, and Jones 2018; Noel et al. 2020) and a lack of charging infrastructure (Giansoldati, Monte, and Scorrano 2020; Noel et al. 2020). However, many regions have achieved longer electric vehicle driving ranges, shorter charging times and more charging infrastructure. Thus, these barriers may become smaller over time.

PEVs' higher purchase prices are cited as another barrier to their adoption (Dua and White 2020; Noel et al. 2020; Adepetu and Keshav 2017; Vassileva and Campillo 2017). This finding mostly comes from studies of economically developed countries. However, PEVs' high purchase prices may be an even greater barrier to adoption in emerging economies, such as India. Studies also find that potential PEV buyers have concerns about battery life (Krupa et al. 2014; Wu, Liao, and Wang 2020). Finally, buyers worry that PEVs may depreciate in value more quickly than comparable ICEVs (Guo and Zhou 2019; Trivedi 2020; Noel et al. 2020).

Despite these barriers, some consumers do choose to purchase PEVs rather than ICEVs. They are motivated to purchase PEVs in part because of their environmental benefits (Dua, White, and Lindland 2019; Axsen, Bailey, and Castro 2015; Higueras-Castillo et al. 2019; Choi and Johnson 2019). Consumers also appreciate PEVs' fast acceleration, as electric motors can deliver peak torque from zero revolutions (Skippon and Garwood 2011; Higueras-Castillo et al. 2019). Finally, consumers cite their lower maintenance and fueling costs relative to ICEVs as a reason for purchasing PEVs (Berkeley, Jarvis, and Jones 2018; Caperello, Kurani, and TyreeHageman 2014).

In addition to these barriers to purchasing, there are some technical barriers to PEV adoption. In particular, although consumers perceive the lack of charging infrastructure as a barrier, developing this infrastructure is also met with some obstacles. In some regions, high land rent prices and a lack of available land for installing chargers have created challenges (Guo, Yang, and Yang 2018; Zhang et al. 2018). The costs of manufacturing and installing electric vehicle charging equipment are also potential barriers (Li and Ouyang 2011; Schroeder and Traber 2012). High commercial electricity costs may hinder the development of charging infrastructure as well. It is difficult for charging companies to develop sustainable business models if the profit margins on the electricity sold are too low (Zhang et al. 2018; Engel et al. 2018). Governments therefore provide grants to offset the high costs of developing and installing charging infrastructure (Nicholas and Hall 2018; IRENA 2019). Researchers also suggest that governments should subsidize charging infrastructure installation.

The lack of local[3] supply chains for the components used to manufacture PEVs and PEV batteries may also hinder the development of a country's PEV market (Zarazua de Rubens et al. 2020; Günther, Kannegiesser, and Autenrieb 2015; Lu et al. 2014). One possible driver of the lack of manufacturing capabilities is that such manufacturing facilities require huge capital investments (Wu et al. 2017; Todd, Chen, and Clogston 2013). Research shows that some automakers may be unwilling to make these investments owing to technology uncertainties, as battery chemistry is continually evolving (Pereirinha et al. 2018).

To help overcome barriers to consumer purchasing, policymakers are utilizing incentives to encourage car buyers to choose PEVs. Financial incentives are designed to make PEVs more affordable. Incentives such as carpool, bus lane access and free parking are designed to make PEVs cheaper and more convenient to own. Research shows that such financial incentives do encourage consumers to purchase PEVs (Hardman 2019, Sheldon and Dua 2019b, 2020, Münzel et al. 2019, Aasness and Odeck 2015, Bjerkan, Nørbech, and Nordtømme 2016, DeShazo 2016). In addition to making PEVs cheaper, governments can make ICEVs more expensive to purchase through taxes. Research shows that such policies are also effective in encouraging consumers to switch to PEVs (Lieven 2015; Wangsness, Proost, and Rødseth 2020). France and Sweden have taken combination approaches of taxing ICEVs and offering incentives to purchase PEVs through feebate systems.

Governments also encourage consumers to choose PEVs by offering license plate and zone restriction exemptions. In some regions, license plate restrictions allow only certain vehicles to use roads on certain days. In others, only a limited number of new license plates can be issued. Some regions in China have introduced exemptions to these types of rules for PEVs (Ma, Fan, and Feng 2017; Ou et al. 2019; He et al. 2018). Similarly, in some European cities, policymakers use congestion or emissions zones to restrict or charge fees to ICEVs.

Policymakers may address the low PEV supply and small local manufacturing bases with mandates requiring automakers to produce and sell PEVs in their region. Globally, the first such regulation to be introduced was the California zero emission vehicle (ZEV) mandate, which nine other United States (U.S.) states have followed. In 2018, China introduced a similar mandate, the new energy vehicle (NEV) policy (Axsen, Plötz, and Wolinetz 2020; Melton, Axsen, and Moawad 2020). Some nations are considering or have begun implementing bans on ICEV sales, which are effectively 100% ZEV sales mandates (Plötz et al. 2019). Additionally, policymakers can provide tax cuts or grants for research and development to help spur the development of domestic PEV supply chains (Lutsey et al. 2018; Ou et al. 2019).

2. Literature Review

Table 1. Specific aspects of the literature explored in our survey.

Factors considered and findings from the literature	Literature	
	Global	India-focused[4]
Consumer adoption of PEVs		
Financial incentives to reduce the upfront costs of PEVs can facilitate adoption; common examples include rebates, tax credits and registration fee waivers, among others	(Hardman 2019; Sheldon and Dua 2019b, 2020; Münzel et al. 2019)	(CEEW 2019)
Reoccurring financial incentives for PEV ownership can enable adoption; common examples including free parking, toll road fee waivers and special lane access, among others	(Hardman 2019)	(CEEW 2019)
PEVs' lower operation and maintenance costs due to their higher fuel economy, lower fuel (electricity) price and fewer moving parts can favor adoption	(Berkeley, Jarvis, and Jones 2018)	(TERI 2019)
PEVs' higher environmental friendliness due to lower or zero tailpipe emissions can drive adoption	(Skippon and Garwood 2011; Higueras-Castillo et al. 2019)	(TERI 2019; Bhalla, Ali, and Nazneen 2018)
PEVs' higher acceleration due to higher instant torque from stored energy can motivate adoption	(Dua and White 2020; Noel et al. 2020)	(TERI 2019)
PEVs' higher upfront purchase prices relative to ICEVs can disincentivize adoption	(Giansoldati, Monte, and Scorrano 2020; Noel et al. 2020)	(TERI 2019; Bansal and Kockelman 2017)
The lack of widespread public charging infrastructure for PEVs can discourage adoption	(Sierzchula et al. 2014)	(TERI 2019)
Fewer dealerships and PEV models on the market can reduce adoption	(Sierzchula et al. 2014)	(TERI 2019; CEEW 2019)
PEVs' lower driving range relative to ICEVs can discourage adoption	(Carley, Siddiki, and Nicholson-Crotty 2019)	(TERI 2019)
PEVs' longer refueling time relative to ICEVs can act as a barrier to adoption	(Berkeley, Jarvis, and Jones 2018; Noel et al. 2020)	(TERI 2019)
Low-interest bank loans for PEV purchases can facilitate adoption	(Tietge et al. 2016)	(Philip 2020; CEEW 2019)
Concerns about the lifespan of PEV batteries can discourage adoption	(Krupa et al. 2014; Wu, Liao, and Wang 2020)	(TERI 2019; Bhaskar 2017)
The lower retention value (i.e., ratio of the resale value to the transaction price) of used PEVs relative to used ICEVs can disincentivize adoption	(Guo and Zhou 2019; Trivedi 2020; Noel et al. 2020)	(CEEW 2019; Philip 2020)
The lack of knowledge about PEVs can discourage adoption	(Jin and Slowik 2017)	(Bansal and Kockelman 2017)
Public charging infrastructure		
A lack of available land and high land rent prices can discourage the installation of public charging stations	Guo, Yang, and Yang 2018; Zhang et al. 2018)	(AEEE 2020; CEEW 2019)
The high capital costs of setting up PEV charging stations can disincentivize the provision of public charging infrastructure	(Li and Ouyang 2011; Schroeder and Traber 2012)	(AEEE 2020; CEEW 2019)
The lack of financing options for installing charging stations, including loans and incentives to reduce upfront investment costs, can limit public charging infrastructure	(Zhang et al. 2018; Hall and Lutsey 2017)	(CEEW 2019; BEE 2019)

The high per-unit cost of electricity for commercial use can discourage both the use and installation of public charging infrastructure by lowering the rate of return on investments	(Zhang et al. 2018; Engel et al. 2018)	(AEEE 2020; CEEW 2019)
Limited buy-in from the distribution companies involved in transmitting and distributing electricity from power utilities can discourage the installation of charging infrastructure	(U.K. Parliament 2018; SEPA 2019)	(BEE 2019)
Subsidies on electricity for public charging can make it profitable to set up public charging infrastructure	(Zhang et al. 2018)	(BEE 2019)
The lack of a local supply chain for components used in manufacturing electric vehicle supply equipment can hinder the installation of public charging infrastructure	(Springer India New Delhi 2012)	(CEEW 2019)
Policy levers to promote PEV adoption		
Vehicle license quota restrictions for non-PEVs with no restrictions for PEVs can facilitate PEV adoption	(Ma, Fan, and Feng 2017; Ou et al. 2019; He et al. 2018)	(ICCT 2019; Dogra 2019)
Low or zero emission zones that allow only PEVs and restrict access by non-PEVs can incentivize PEV adoption	(ICCT 2020)	(ICCT 2019)
Various forms of investments in public charging infrastructure, including government grants, capital incentives and tax cut incentives, can support PEV adoption	(Nicholas and Hall 2018; IRENA 2019)	(BEE 2019)
Non-financial and financial incentives, including upfront price reductions, rebates, tax credits and registration fee waivers, enable PEV adoption	(Hardman 2019; Sheldon and Dua 2019a, 2019b)	(NITI Aayog & RMI India 2019; BEE 2019)
PEV mandates that require automakers to sell a minimum share of ZEVs, such as the ZEV mandates in some U.S. states and China's NEV policy, can promote PEV adoption	(Axsen, Plötz, and Wolinetz 2020; Melton, Axsen, and Moawad 2020)	(NITI Aayog 2018)
Raising taxes on conventional gasoline and diesel fuels can encourage PEV adoption	(Lieven 2015; Wangsness, Proost, and Rødseth 2020)	(ICCT 2019; CEEW 2018)
Banning new ICEV sales can increase PEV adoption	Hardman and Sperling 2019; Senecal and Leach 2019; Plötz et al. 2019)	(Economic Times 2019)
More credits for PEV sales in corporate average fuel economy (CAFE) norms can promote PEV adoption	(Axsen, Plötz, and Wolinetz 2020; Sen, Noori, and Tatari 2017; Jenn, Azevedo, and Michalek 2016)	(Vardhini C 2019; Ministry of Heavy Industries & Public Enterprises 2018)
Feebates, which entail taxes on fuel-inefficient vehicles and rebates for fuel-efficient vehicles, can favor PEV adoption	(Greene et al. 2005; de Haan, Mueller, and Scholz 2009)	(NITI Aayog and RMI India 2017)
Manufacturing PEVs and batteries for PEVs		
The lack of local supply chains for components used in PEV and PEV battery manufacturing, including mineral resources, semiconductors, motors, controllers and power electronics, discourages local manufacturing	Zarazua de Rubens et al. 2020; Günther, Kannegiesser, and Autenrieb 2015; Lu et al. 2014)	(ICRIER 2019)
Greater local demand for finished products (i.e., PEV batteries and PEVs) can encourage domestic manufacturing	(Lu et al. 2014; Todd, Chen, and Clogston 2013)	(Ernst & Young 2017)

Support policies, including incentives to reduce upfront investment costs, tax cut incentives, research and development grants, ease of business incentives and reduced utility rates, can facilitate domestic manufacturing	(Lutsey et al. 2018; Ou et al. 2019)	(CEEW 2019; NITI Aayog & RMI India 2019)
Huge capital requirements and difficulties raising the capital to set up a manufacturing plant can act as a barrier to domestic manufacturing	(Wu et al. 2017; Todd, Chen, and Clogston 2013)	Deloitte 2019; CEEW 2019)
Technology uncertainties, such as the rapidly evolving chemistry of PEV batteries, can act as a disabler for manufacturing investments	(Pereirinha et al. 2018)	(Ernst & Young 2017; ICRIER 2019)
The lack of skilled workers specifically trained in battery and PEV powertrain manufacturing can discourage local manufacturing	(Naumanen et al. 2019; Merz and Stevenson 1995)	(CEEW 2019)
The lack of an established PEV after-sales ecosystem, including maintenance service, aftermarket components and markets for used batteries and PEVs, can act as a barrier to domestic manufacturing	Dombrowski and Engel 2013, 2014)	(Deloitte 2019; ICRIER 2019)
Societal Gains from PEV Adoption		
PEV adoption can result in reduced air pollution and improvements in city-level air quality	(Razeghi et al. 2016; Gai et al. 2020)	(IIT Madras & WRI India 2019; NITI Aayog & RMI India 2019)
PEV adoption can reduce consumption of transportation fuels, including petrol and diesel	(Sheldon and Dua 2018)	(IIT Madras & WRI India 2019; NITI Aayog & RMI India 2019)
PEV adoption can help mitigate climate change through GHG emissions reductions	(Lutsey 2015; Zheng et al. 2020)	(IIT Madras & WRI India 2019; NITI Aayog & RMI India 2019)
PEV adoption can reduce crude oil imports, leading to cost savings and lower energy dependence	(BP 2016; Kah 2018; Albrahim et al. 2019)	(IIT Madras & WRI India 2019; NITI Aayog & RMI India 2019)

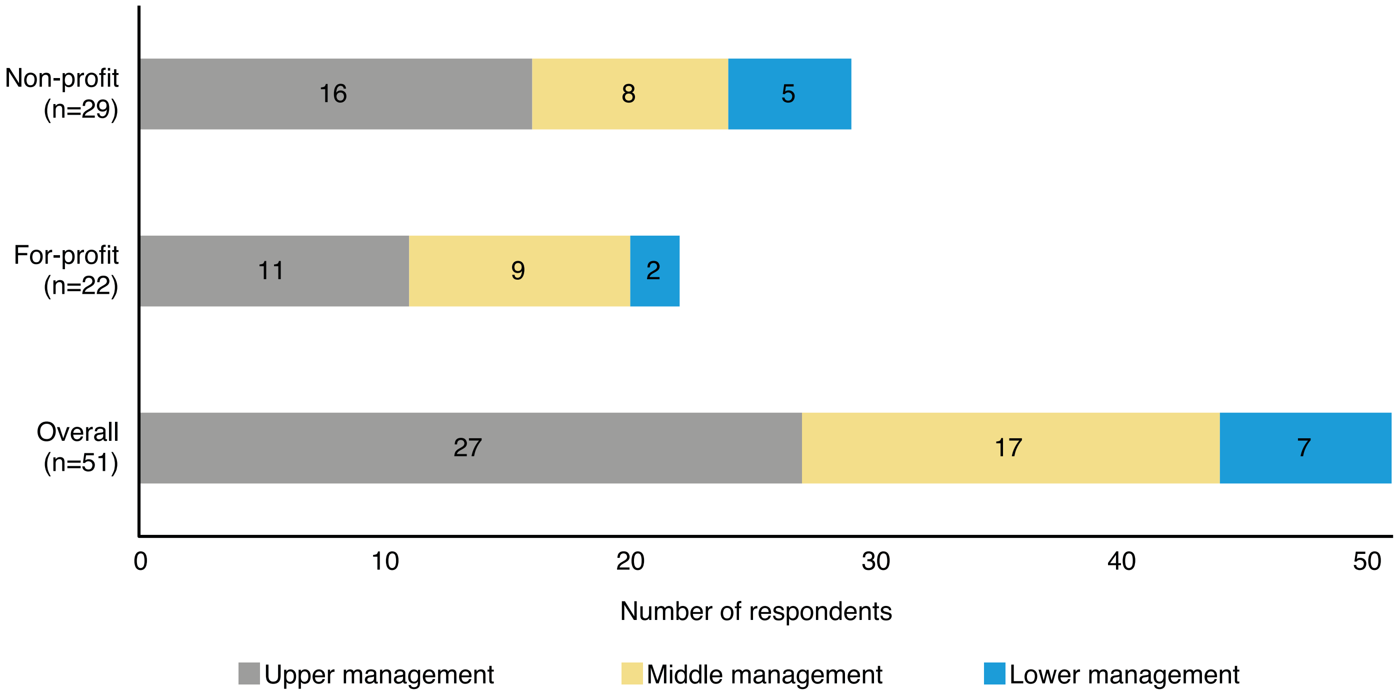
3. Methods

Study Population

We identified a study population of 152 PEV experts who are key participants in the current PEV debate. We specifically aimed to ensure a range of experience among the experts. The study population represents both the for-profit and non-profit sectors and includes experts from manufacturing companies, power utility companies, government ministries and think tanks. We identified these experts from the literature on India's LDV sector and conference participation lists. We also targeted members of relevant associations, such as the Society of Manufacturers of Electric Vehicles and the Society of Indian Automobile Manufacturers. Each expert was identified as influencing discussions on the Indian LDV sector and the PEV ecosystem in particular.

We administered an online survey to the 152 selected experts between March and June 2020. In total, 51 experts completed the survey.[5] Figure 1 shows the distribution of the survey respondents across various sectors and levels of seniority.

Figure 1. Distribution of respondents across sectors and levels of seniority.



Source: KAPSARC analysis.

Survey Outline

We solicited the experts' opinions on six different themes related to India's PEV ecosystem. These themes include PEVs' expected share of new sales by 2030, factors influencing consumer adoption, and public charging infrastructure and the impact on the electricity sector. We also asked about policy levers for meeting India's aspirational PEV target by 2030, factors influencing local PEV and PEV battery manufacturing, and potential societal impacts. For each theme, respondents were asked a series of questions with possible answers on either a three-point or a five-point Likert-type scale (Sullivan and Artino Jr. 2013). The experts were also asked to rate enablers and disablers on a five-point Likert-type agreement scale. After these questions, the respondents were asked to select the most important enabler and disabler.

Statistical Analysis

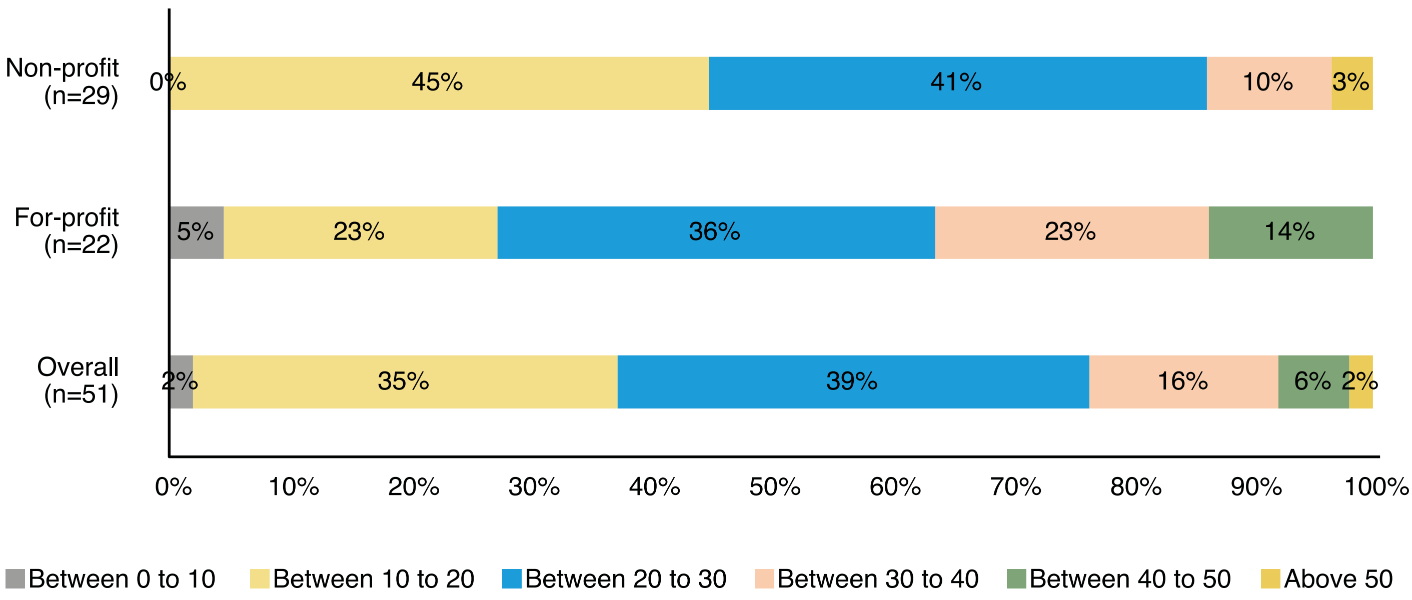
Given the discrete, ordinal nature of the survey data items, non-parametric tests are most appropriate for this analysis (Sullivan and Artino Jr. 2013). Thus, we use the Mann-Whitney equality-of-medians test, which is non-parametric, to analyze the survey data. This test compares two medians to determine whether they are significantly different from each other.

4. Results

Expected Share of PEV Sales by 2030

Respondents were asked what they expected PEVs' annual share of new sales in India to be by 2030. The respondents could choose a percentage range of 0-10, 10-20, 20-30, 30-40, 40-50 or greater than 50. Figure 2 shows the distribution of responses among the experts from the for-profit and non-profit sectors.[6] The bar labelled "overall" shows the results for both respondent groups combined. On average, the minimum expected market share is 19.4%, and the maximum expected market share is 30.2%, with an average expected market share of around 24.8%.[7]

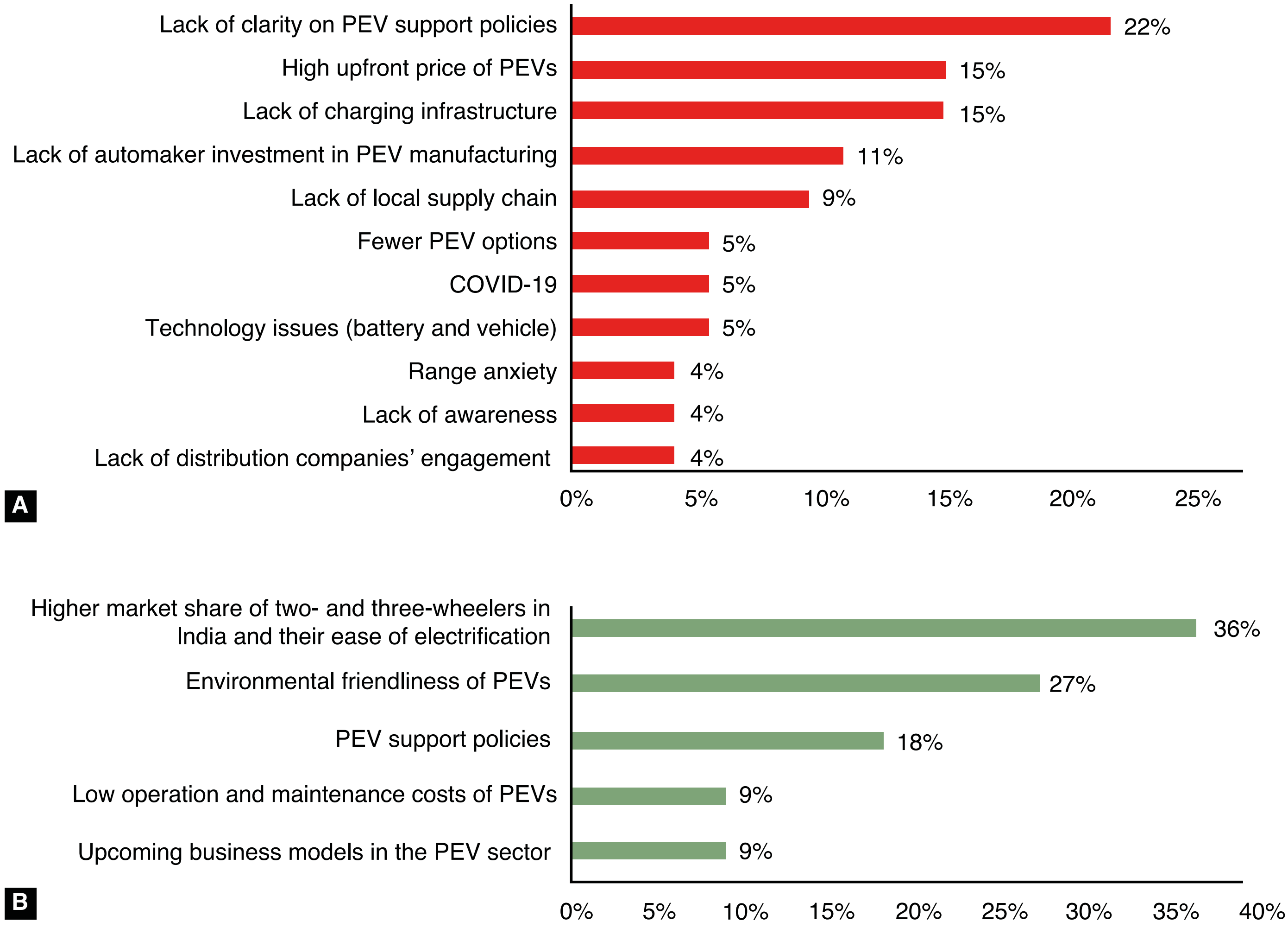
Figure 2. Respondents' expectations of PEVs' annual share of new sales in India by 2030.



Source: KAPSARC analysis.

We asked the respondents to explain their choice of expected PEV market share range. We also asked why they thought India would fall short of or surpass its aspirational goal of a 30% market share for PEVs. Figure 3 shows the reasons cited by the respondents. Of the 51 respondents, 39 (~76%) believe that India will fail to achieve its aspirational goal. The lack of government policies, the high upfront price of PEVs and the lack of charging infrastructure are the top three reasons for this belief. An additional 12 (~24%) respondents believe that India will surpass its aspirational target. They listed the aggressive government push toward the electrification of the two- and three-wheeler segments and PEVs' environmental benefits as important reasons for this belief.

Figure 3. Stated reasons that India will (a) underachieve or (b) overachieve its aspirational target of a 30% new sales share for PEVs by 2030.



Source: KAPSARC analysis.

Factors Influencing Consumer Adoption of PEVs in India

Next, we asked the experts about the factors that are encouraging or discouraging Indian consumers from adopting PEVs. Figure 4a shows the respondents' ratings of various enablers and disablers on a Likert-type scale ranging from "strongly agree" to "strongly disagree." Figure 4b shows the distribution of the respondents' choices of the most important enabler and disabler.

Figure 4 illustrates three notable results. First, the "higher upfront price of PEVs" is seen as the most important disabler, as it was cited by 63% of the respondents. In line with this result,[8] 80% of the respondents selected "financial incentives to reduce upfront costs" as the most important enabler.

On the Likert-type scale, these choices had the highest percentages of “strongly agree” responses in the disabler and enabler categories, respectively.[9] For-profit respondents rated financial incentives as a more important enabler than did non-profit respondents.[10] However, the two groups’ ratings of the “higher upfront price” disabler are not statistically different.[11]

The second notable result relates to the remaining important barriers. The “lack of charging infrastructure” is seen as the second-most important barrier, as it was selected by 20% of the respondents. “Fewer PEV options,” which was selected by 6% of the respondents, is the third-most important barrier. The Likert-type scale responses to the “lack of charging infrastructure” barrier are statistically different from those to the remaining disablers. However, the Likert-type scale responses to “fewer PEV options” are not statistically different from the responses to the remaining disablers.[12] Non-profit respondents rate the “lack of charging infrastructure” as a more important disabler than do for-profit respondents.[13]

The third notable result relates to the remaining important enablers. “Lower operation (fuel) and maintenance costs” is the second-most important enabler, selected by 14% of the respondents. “Reoccurring financial incentives from owning PEVs,” selected by 6% of the respondents, is the third-most important enabler. The Likert-type scale responses to these two enablers are not statistically different from each other. However, they are statistically different from the responses to the remaining enablers.[14] The responses to these two enablers among for-profit and non-profit respondents are not statistically different.[15]

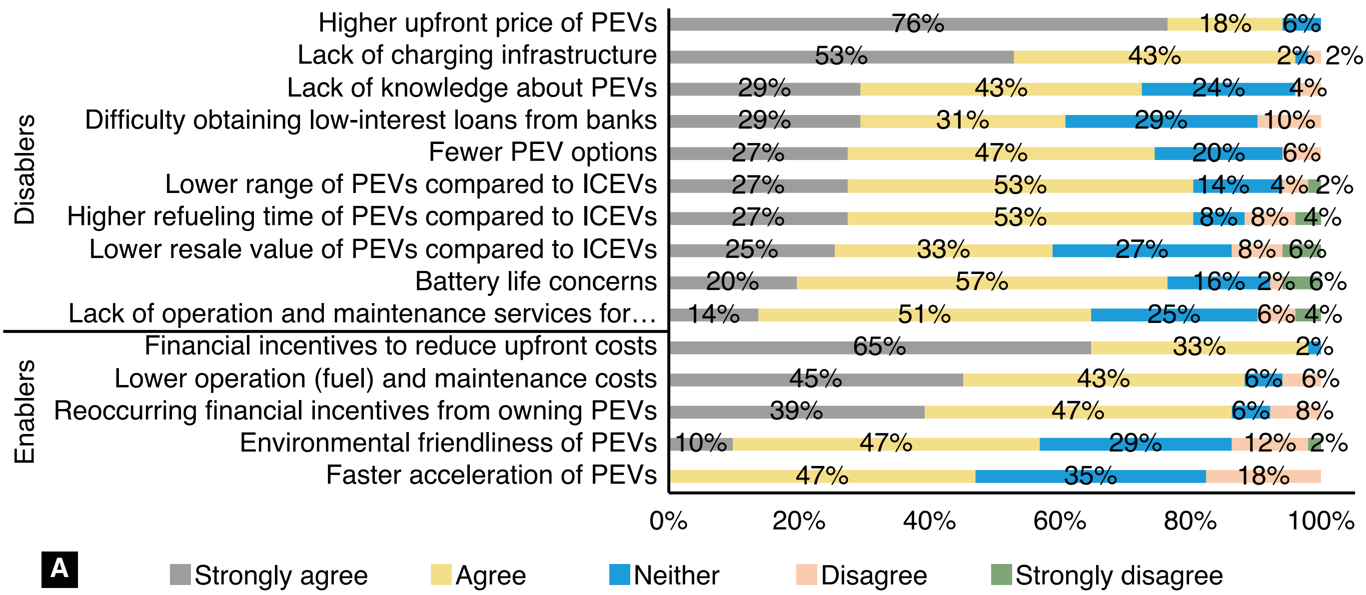
Public Charging Infrastructure

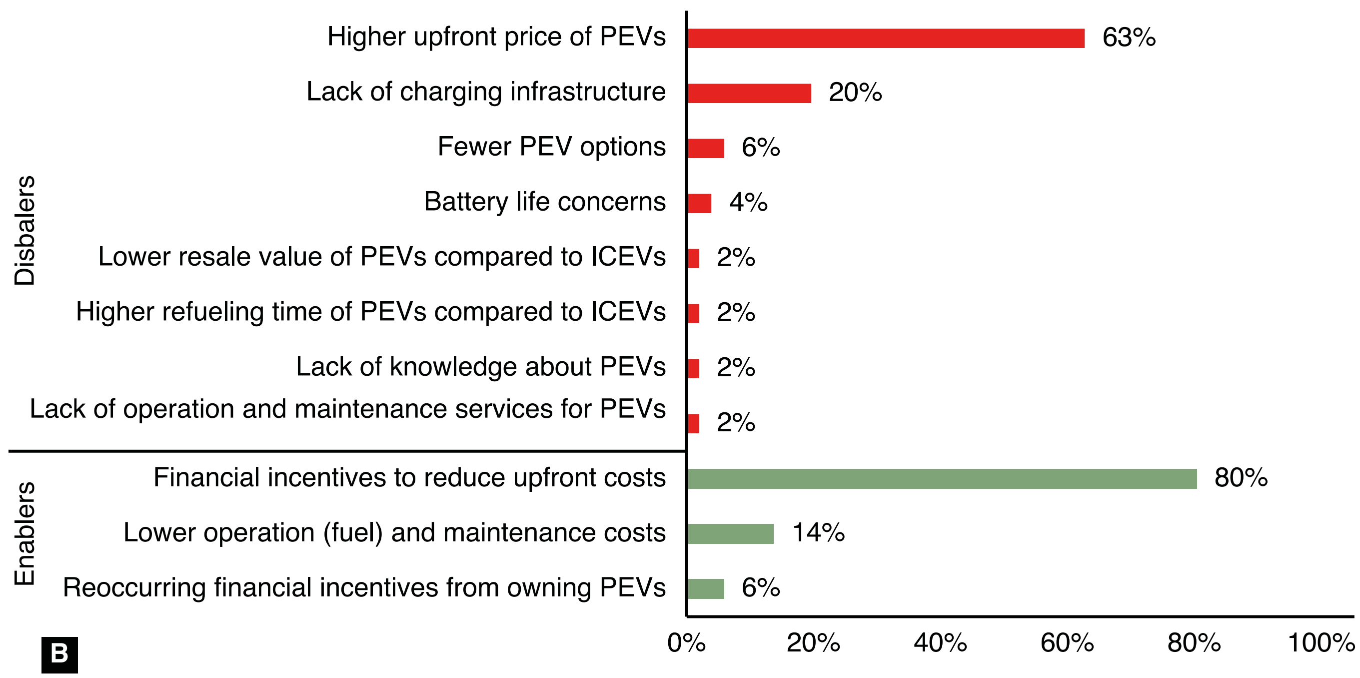
As this analysis shows, experts believe that the lack of public charging infrastructure is the second-most important barrier to PEV adoption in India. We therefore asked respondents about the reasons for India’s inadequate public charging infrastructure. Figure 5a shows the respondents’ ratings of various factors related to the public charging infrastructure on the Likert-type scale used for the previous question. Figure 5b presents the distribution of their responses to a question about the most important barrier to this infrastructure.

Figure 5 presents three notable results. First, the “lack of land availability and high land rent prices” received the most “strongly agree” responses (55%). The response distribution for this barrier is statistically different from those for the other barriers.[16] Furthermore, the greatest number of respondents (47%) selected this barrier as the most important one. Second, about 27% of respondents cited the “high cost of setting up a PEV charging station” as the most important barrier. However, this barrier’s response distribution is not statistically different from the response distribution of the “lack of financing options for setting up charging stations.”[17] Third, for each of the top three barriers, the responses of the for-profit and non-profit respondents are not significantly different.[18]

4. Results

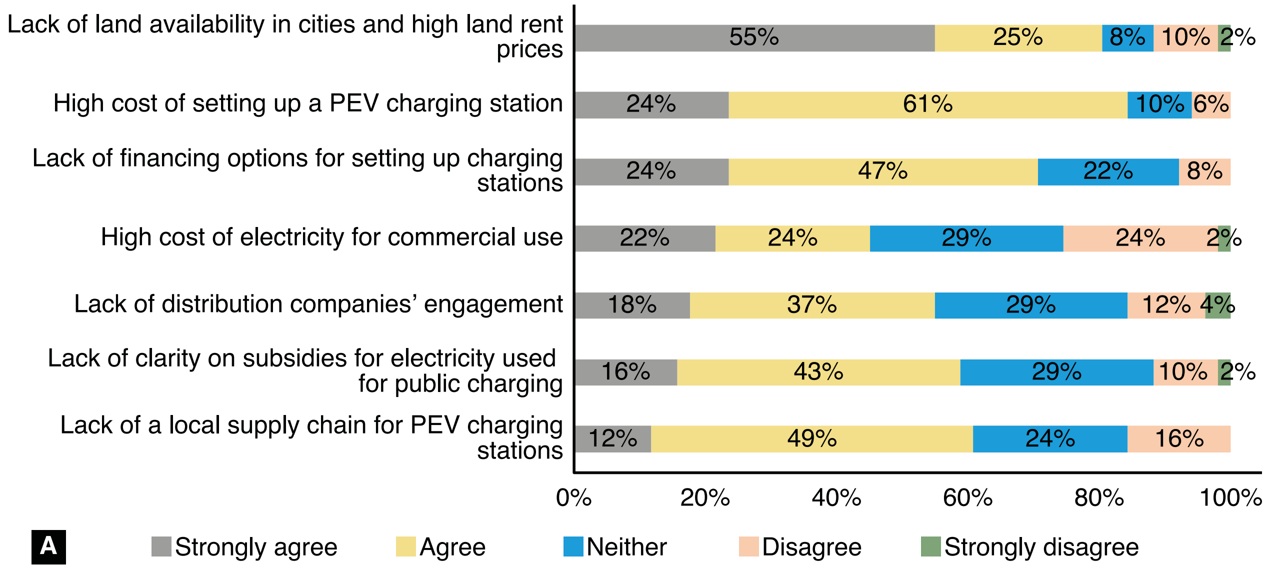
Figure 4. Respondents' beliefs about (a) whether various factors are enablers or disablers of consumer adoption of PEVs in India and (b) the most important enablers or disablers.

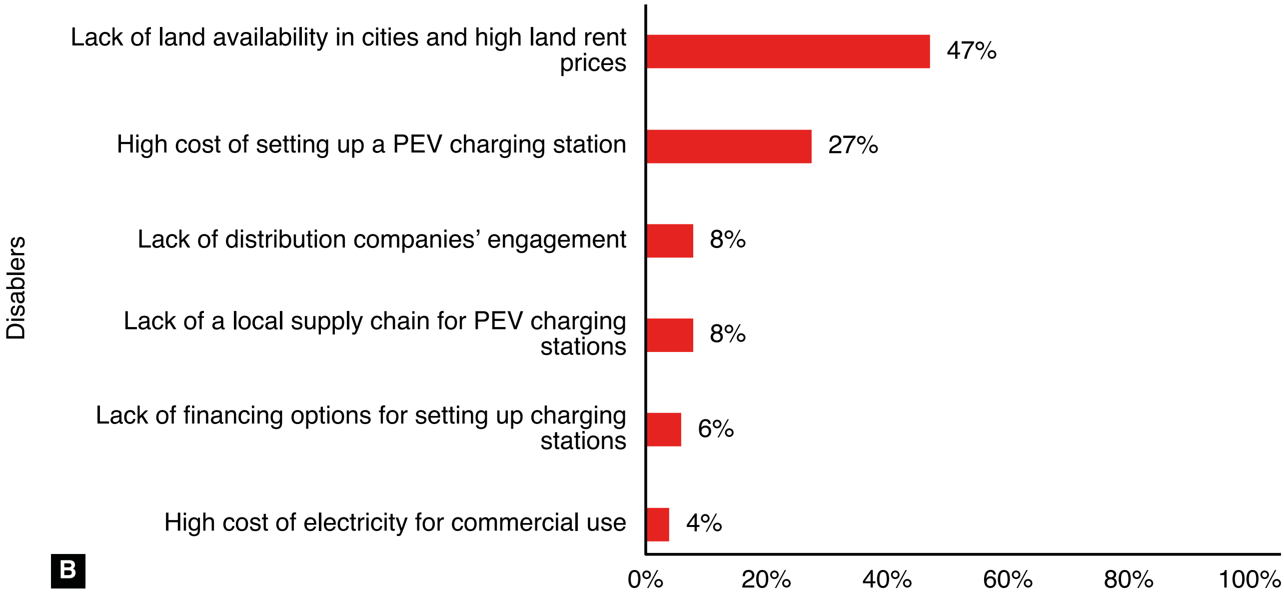




Source: KAPSARC analysis.

Figure 5. Respondents' (a) levels of agreement or disagreement with statements related to the public charging infrastructure and (b) beliefs about the greatest barrier to PEV market development.





Source: KAPSARC analysis.

Policy Levers to Meet the Aspirational Target of a 30% Annual Share for PEV Sales by 2030

We sought experts' opinions on the policy levers that can help India achieve a 30% annual share of new sales for PEVs by 2030. We asked about policies at both the central and state levels. Figure 6a shows the responses to a survey question asking the experts to rate various enablers and disablers. This question uses the same Likert-type scale as in the previous questions. Figure 6b shows the rankings of the most important enablers and disablers according to the respondents.

Figure 6 offers three notable results. First, the respondents most frequently (33%) chose a PEV mandate as the most important lever at the national level. A feebate policy ranked as a close second (29%). The response distributions for these two policy levers on a Likert-type scale are not statistically different.[19] In other words, when rating the two policy levers independently, experts indicated that the policies are equally able to help India achieve its aspirational target for 2030. However, when asked to select a single most important policy lever, slightly more respondents chose a PEV mandate policy than a feebate policy.

Second, we observe similar trends for state-level policy levers. Most of the respondents chose a PEV mandate[20] (41%), followed by incentives for PEVs (31%). However, the response distributions for the four state policy levers on a Likert-type scale are not statistically different.[21]

Third, the Likert-type scale responses of the for-profit and non-profit respondents are not statistically different for PEV mandate policy levers.[22] In fact, the responses of the for-profit and non-profit respondents are not statistically different for any of the state- or national-level policy measures.[23]

Factors Influencing PEV and PEV Battery Manufacturing in India

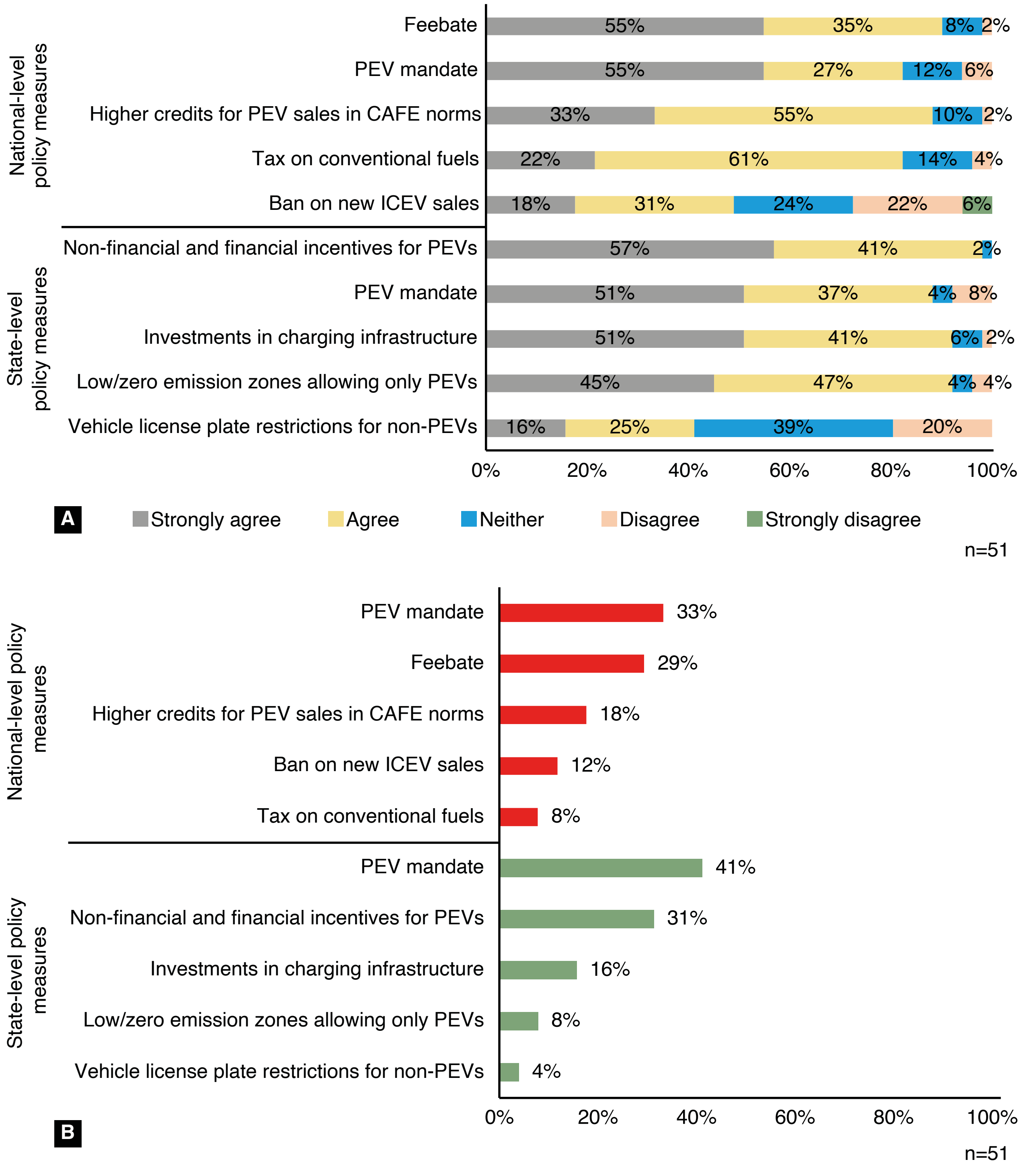
We also sought experts' opinions on the factors influencing local PEV and PEV battery manufacturing. Figures 7a and 8a show the respondents' ratings of various enablers and disablers, respectively, on the same Likert-type scale as in the prior analyses. Figures 7b and 8b illustrate the distributions of the respondents' choices of the most important enabler and disabler, respectively.

Figures 7 and 8 suggest three notable results. First, the respondents most frequently chose "lack of local demand for PEVs" as the single most important barrier to both PEV and PEV battery manufacturing. This barrier also received the greatest number of "strongly agree" responses to the Likert-type scale question. However, its overall distribution on the Likert-type scale is not statistically different from those of three other barriers for both types of manufacturing. The other important barriers are "lack of clarity on manufacturing support policies at the central and state levels," "lack of local supply chains for batteries, motors, controllers, and power electronics" and "difficulty raising capital for PEV development and manufacturing."[24] Although the "lack of local demand for PEVs" must be overcome first, the other three barriers to manufacturing must be addressed as well.

Second, "incentives for reducing upfront investment costs" was most frequently listed as the most important enabler of both types of manufacturing. The second-most important enablers are "tax cut incentives" for PEV manufacturing and "grants for research and development" for battery manufacturing.[25] However, on the Likert-type scale, the response distributions for "incentives for reducing upfront investment costs" and "tax cut incentives" are not statistically different for either type of manufacturing.

Third, for-profit experts rate the importance of "incentives for reducing upfront investment costs" relatively higher. This result is fairly intuitive.[27] However, the for-profit and non-profit experts' responses for the "lack of local demand for PEVs" are not significantly different.[28]

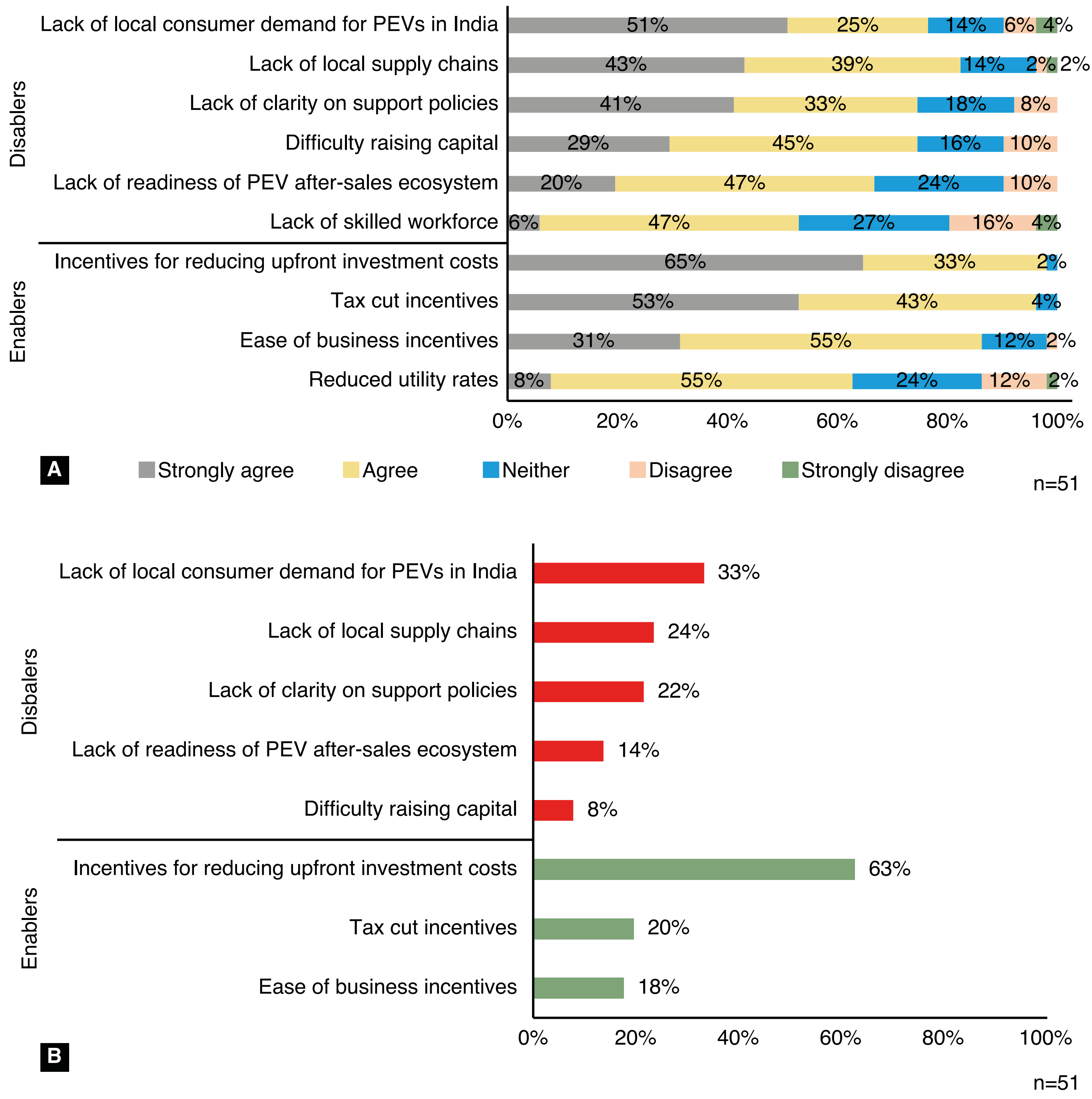
Figure 6. Respondents' (a) agreement or disagreement with the ability of national- and state-level policy measures to help achieve the 2030 targets and (b) beliefs about the most important measures.



Source: KAPSARC analysis.

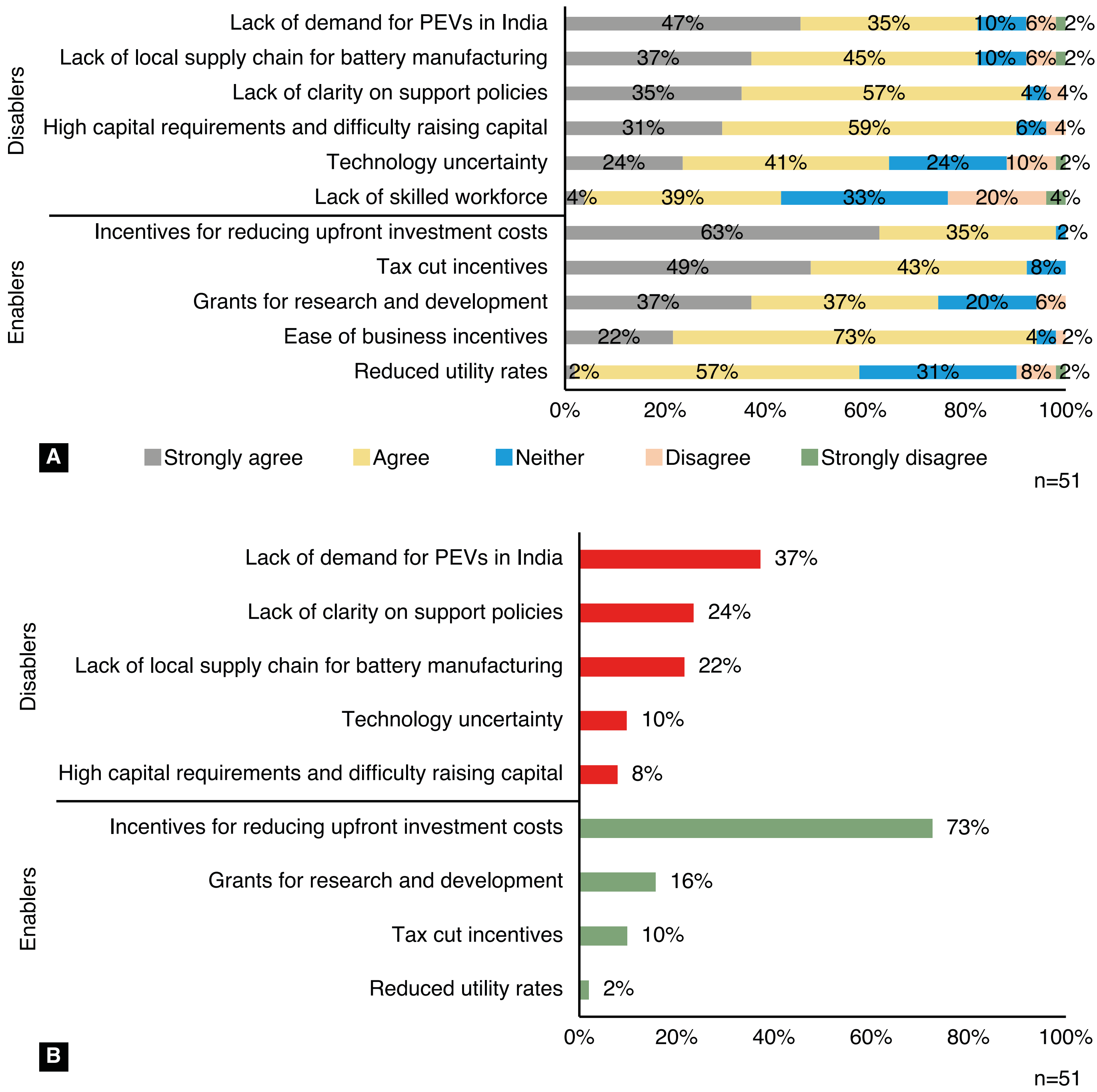
4. Results

Figure 7. Factors influencing domestic PEV manufacturing in India.



Source: KAPSARC analysis.

Figure 8. Factors influencing domestic PEV battery manufacturing in India.



Source: KAPSARC analysis.

Potential Societal Impact

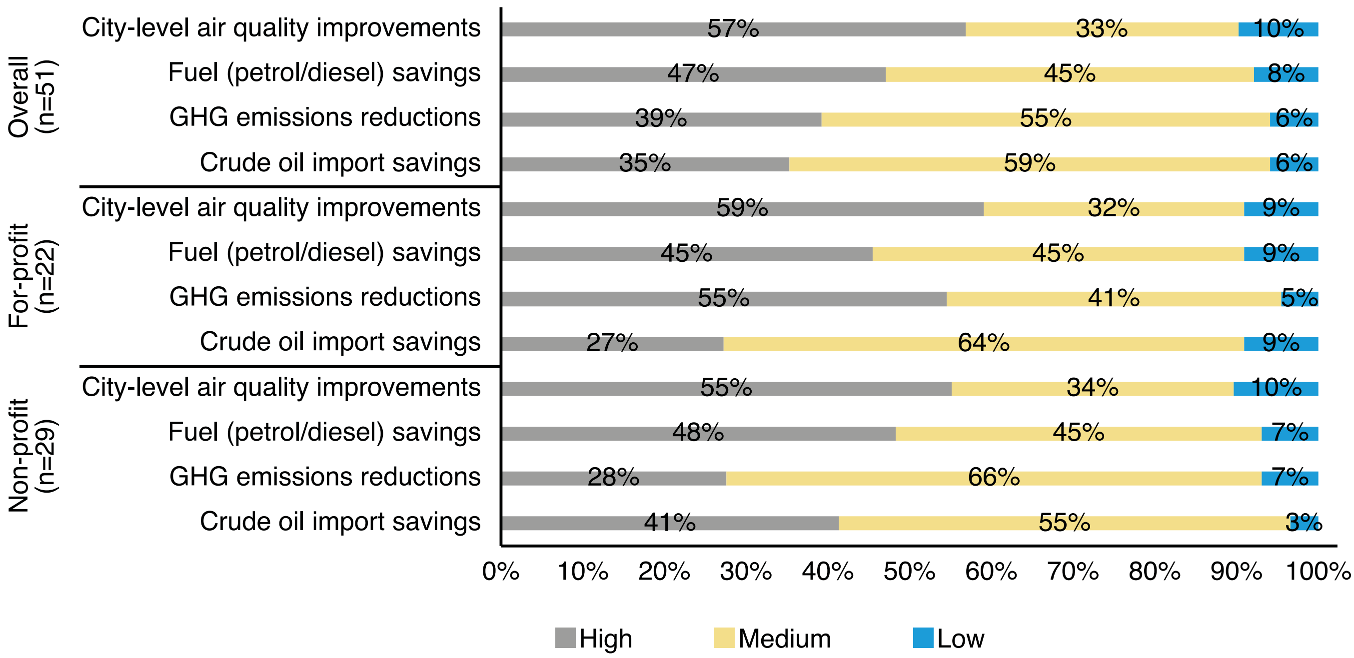
PEV adoption is considered a potential solution to the issues of air pollution, energy security and climate change. Thus, we asked the respondents to rate the extent of the potential societal gains if India meets its aspirational PEV sales target by 2030. Specifically, we asked them about crude oil import reductions, fuel (petrol and diesel) savings, GHG emissions reductions and city-level air quality improvements. Figure 9 shows the respondents' expectations along these dimensions.

We find three notable results. First, the respondents expect similar medium-to-high gains on all four dimensions. Second, the respondents' ratings are significantly different for two of the four potential areas of societal gain: city-level air quality improvements and crude oil import reductions.[29]

The respondents' expectations may be relatively higher for city-level air quality improvements because PEVs have no tailpipe emissions. The emissions associated with electricity generation, which is necessary for PEVs, occur around power generation plants, which are typically near or outside city peripheries. Thus, the emissions associated with vehicle use within cities are expected to decline the most as PEV penetration increases.

Third, we observe statistical differences across for-profit and non-profit experts' responses only for the extent of GHG emissions reductions.[30] Respondents from for-profit institutions are more optimistic about the extent of GHG emissions reductions than their counterparts from non-profit institutions. The responses of the for-profit and non-profit experts are not statistically different at the 10% level for the other societal gain areas.

Figure 9. Extent of the expected societal gains from achieving the aspirational PEV sales target by 2030.



Source: KAPSARC analysis.

5. Discussion

The experts surveyed in this study largely expect that India will not reach its PEV market goals by 2030. The main reasons cited for this prediction are the lack of PEV-promoting policies, the high upfront price of PEVs and the lack of charging infrastructure. The experts cite subsidies for PEVs as the most important enabler for mitigating the barrier of high upfront PEV prices. Public investments in charging infrastructure may be a viable policy solution to the lack of charging infrastructure.

Notably, the Indian government recently allocated a budget of 10,000 crore rupees (~$1.4 billion in 2019 dollars) over three years to address the latter two barriers. This budget is part of the recent Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) II scheme.[31] Approximately 86% of this funding is set aside for demand incentives for EV purchases, and 10% is allocated to building charging infrastructure (Ministry of Heavy Industries and Public Enterprises 2019b).[32]

Additionally, the Indian Ministry of Road Transport and Highways (MoRTH) recently launched a new policy initiative based on a battery-as-a-service business model. This initiative intends to reduce the upfront price of PEVs. The ministry issued a notification in August 2020 that allows the sale of electric two- and three-wheelers without pre-fitted batteries (Government of India 2020). Batteries can account for nearly 40% of a PEV's cost (Cruze 2020). Thus, the MoRTH argued that electric two- and three-wheelers may cost less than their ICEV counterparts if battery and vehicle costs are delinked. With this program, batteries can be provided separately either by vehicle makers or by energy service providers using a service model (Chaliawala 2020). In the latter case, an energy service provider may rent charged batteries to EV owners, thereby promoting battery swapping. This model can also address consumers' concerns about the longer refueling times of PEVs relative to ICEVs. However, the ministry's notification caused confusion among manufacturers. It was unclear whether PEVs sold without batteries would qualify for subsidies under the FAME II scheme. Additionally, the distribution of subsidies between vehicle manufacturers and energy service providers was unclear (N. Sharma 2020). Manufacturers also needed clarification on potential issues related to battery integration, safety, warranties and standardization.

Almost half of the experts cited the lack of land availability and high land rent prices as the most important reasons for India's lack of adequate public charging infrastructure. The high cost of setting up this infrastructure was cited as the second-most important reason. These issues are likely to increase the burden on the government for setting up this infrastructure. In other countries, governments have largely funded early charging infrastructure on their own (Hall and Lutsey 2017). However, given India's ambitious sales targets, commercially sustainable business models for charging infrastructure are expected to emerge. Automakers and utility companies both have stand-alone models for such infrastructure.

Because the potential revenue from charging is low, it is difficult for infrastructure providers to justify the large upfront investments. To overcome this issue, India's central and state governments are offering capital subsidies to cover charger and installation costs (Government of National Capital Territory of Delhi 2020; Ministry of Heavy Industries and Public Enterprises 2019b). The central government recently approved funding for up to 2,636 charging stations in 62 cities across 24 states and union territories. Of them, 1,633 will be fast charging stations, and the remaining 1,003 will be slow charging stations. The initial budget outlay for this subsidy will be 1,000 crore rupees (~$0.14 billion in 2019 dollars)

(Rawat 2020; Ministry of Heavy Industries and Public Enterprises 2019b). These charging stations can leverage the incentives offered under the FAME II scheme (Ministry of Heavy Industries and Public Enterprises 2019a).

Experts believe that the most impactful policies in helping India meet its aspirational PEV target by 2030 will be PEV mandates and feebate policies. We can categorize the various policy levers at the central and state levels as command-and-control (CAC) or market-based instruments. Based on this classification, we observe that more experts (53%–63%) believe that CAC policies will have the greatest impact on India's vehicle electrification.[33] CAC policies are less transparent and transfer the visible responsibility for issues facing consumers away from the government. This distinction may explain why experts believe that such policies are more likely to be adopted and be impactful in the world's largest democracy (Belzer 2007).

National Institution for Transforming India (NITI) Aayog, an Indian governmental think tank, has suggested a feebate policy worth 7,500 crore rupees (~$1.1 billion in 2019 dollars) (Luthra 2018; NITI Aayog and RMI India 2017; Ganguly 2019). This feebate policy is revenue-neutral. Specifically, it involves increasing taxes on ICEVs to create a surplus that can be used to subsidize PEVs. However, this plan was reportedly suspended in March 2019. The government suspected that financial burdens on automobile buyers may have affected their sentiments ahead of the national elections in 2019 (Phule 2019; Ganguly 2019).

We asked experts for their opinions on the likelihood that a ban on new ICEV sales would be implemented in India by 2030. A majority of the respondents (78%) believed that such a ban was unlikely to be implemented. Only 6% of the respondents believed that it was likely to be implemented, with the remaining experts indicating that they were unsure. These findings are in line with recent statements by India's Minister of Road Transport and Highways ending any speculation regarding an ICEV sales ban (ET Bureau 2019). The minister's statement was in response to NITI Aayog's proposal for a complete switch to electric two- and three-wheelers by 2023 (Soni 2019). This proposal also discussed banning all three-wheeler ICEVs by March 2023 and all two-wheeler ICEVs below 150 cubic centimeters by 2025.

The experts believe that certain barriers must be overcome to facilitate local PEV and battery manufacturing. These barriers include low local demand for PEVs, a lack of favorable manufacturing support policies and no local supply chain. Efforts are underway to stimulate local PEV demand, as outlined in the previous paragraphs. The experts cited reducing upfront investment costs and providing tax cuts as the most important policy enablers of PEV manufacturing. In 2019, the Union Cabinet approved a phased manufacturing program for electric vehicle components and batteries under the National Mission on Transformative Mobility and Battery Storage (Union Cabinet 2019). This program aims to support the establishment of large, export-competitive integrated battery and cell-manufacturing gigafactories in India with a total capacity of 50 gigawatthours (Y. Sharma 2020). The government will incentivize the local production of batteries and their sub-components. Manufacturers can expect to receive incentives close to $25 per kWh (Kohli 2020). In addition, multiple states, including Gujarat, Andhra Pradesh, Karnataka and Maharashtra, are matching the central government's capital subsidies. They are also willing to support these gigafactories' infrastructural needs by offering subsidies on land, capital and utilities (Kohli 2020).

To address the lack of a supply chain for PEV components and encourage localized production throughout the value chain, India's government is disincentivizing high-scale imports. For example, the central government's incentives for gigafactories are related to their levels of indigenization. Specifically, these companies will be eligible for central government subsidies if they achieve 60% indigenization by 2025, when they are expected to attain full-scale production (Sharma 2020b).

The analytical approach utilized in this study provides only qualitative results. In other words, the study qualitatively identifies potential disablers and enablers, their likely impacts on PEV market creation and the associated societal gains. However, we cannot quantify the magnitudes of these impacts. To partially address this limitation, we utilize an open-source simulator to estimate India's potential GHG emissions reduction if it achieves its aspirational PEV target. Specifically, we use the India Energy Policy Simulator (EPS), an open-source model based on system dynamics. This model was originally created by Energy Innovation LLC and was adapted for India in partnership with World Resources Institute India (Energy Innovation 2020). The EPS model was recently used to analyze the likelihood that China's current policies will reduce GHG emissions in accordance with its Paris commitments (Gallagher et al. 2019).

We investigate two scenarios to capture India's expected GHG emissions reduction if it achieves its aspirational PEV target. The first is a scenario in which PEVs reach a 30% share of new sales in India by 2030.[34] The second is the EPS's built-in business-as-usual (BAU) scenario. The BAU scenario results in a PEV market share of 21% by 2030. Achieving a 30% PEV market share in 2030 can reduce GHG emissions by an additional 4 million metric tonnes (mt) annually relative to the BAU scenario.[35]

To put this reduction in context, the IEA (2019a) reports total GHG emissions from fuel combustion for 144 countries. Of them, 46 had total carbon dioxide emissions from the transport sector below 4 million mt in 2017 (IEA 2019a). Moreover, Bayer and Aklin (2020) estimate that the EU Emissions Trading System, the world's largest carbon market, reduced emissions by a cumulative 1.2 billion mt between 2008 and 2016. The average reduction was 5.4 million mt per year for each included country. These comparisons suggest that India can substantially impact global CO_2 emissions relative to a BAU scenario by achieving its aspirational PEV target.

6. Conclusion

Transitioning to PEVs can help India achieve its goals of improving energy security, reducing local air pollution and making its nationally determined contributions to the United Nations Framework Convention on Climate Change. We used a survey instrument to gauge experts' opinions on the disabling and enabling factors in India meeting its PEV targets.

The majority (39/51) of respondents believe that India will not meet its aspirational target of a 30% market share for PEVs by 2030. However, they do not expect India to miss the target by much, as the overall expected market share in 2030 is around 25%. Most respondents (33%) believe that a PEV mandate is the policy measure that can best help India achieve its goal. A feebate policy was the second-most frequently selected (29%). Only a few respondents (6%) believe that a policy banning new ICEV sales in India is likely to be implemented by 2030.

The largest number of respondents (63%) rated the high upfront price of PEVs as the most substantial barrier to adoption. Another 20% selected the lack of adequate public charging infrastructure. Subsidies for PEV purchases were selected by 80% of respondents as the most important enabler to address PEVs' high upfront prices. The respondents also believe that the lack of land availability and high land rent prices must be addressed to ensure adequate public charging infrastructure.

Some nations' automobile markets mostly comprise imported vehicles. In contrast, 84% of the vehicles in the Indian car market are produced in India (SIAM 2019). Many of these vehicle models are specific to the Indian market and often cost less than those sold in other countries. For example, an average new car costs around $12,000 in India but around $34,000 in the U.S. (IEA 2019b). India may not be able to rely on imported PEVs from other countries, as imported vehicles are likely to cost more than Indian consumers typically spend.[36] Thus, the development of domestic PEV manufacturing is important for India to meet its electrification goals. The experts surveyed in this study recognize domestic PEV manufacturing as the key to success in India's PEV market.

Given India's goal of becoming a global PEV manufacturing hub, we also emphasize four major barriers to PEV manufacturing cited by the respondents. These barriers include a lack of local consumer demand for PEVs and a lack of clarity on manufacturing support policies at the national and state levels. They also include a lack of local supply chains for PEV components, including batteries, and difficulty raising capital for PEV development and manufacturing. Incentives reducing upfront investment costs and tax cuts were rated as the most important enablers of local manufacturing by 63% and 20% of respondents, respectively.

Finally, experts believe that India can achieve medium to high societal gains by meeting its aspirational targets. These gains will accrue in city-level air quality improvements, fuel (petrol and diesel) savings, GHG emissions reductions and crude oil import reductions. We used the India EPS model to evaluate the gains from achieving India's aspirational PEV target relative to the BAU scenario. The BAU scenario assumes 21% PEV adoption by 2030, and the aspirational target assumes 30% PEV adoption. Achieving the aspirational target reduces GHG emissions by an additional 4 million mt per year. It also lowers crude oil imports by an additional 23.6 million barrels per year in 2030.

Most current research on PEV adoption focuses on developed markets. This study's results highlight the need to consider different factors to help India's PEV market mature. Both India and more developed markets have some common barriers to PEV adoption, including costs and infrastructure gaps. However, the ways that these barriers manifest and the best solutions may differ between India and more developed countries. Purchase price barriers may be more extreme in India because its car buyers have lower incomes than buyers in more developed nations. This higher price sensitivity increases the need to reduce battery costs through manufacturing economies of scale and innovative policy-driven business models. For example, the Indian government is currently developing a battery-as-a-service model. Second, public charging infrastructure barriers are also critical to address. Relative to developed countries, a greater proportion of India's population lives in apartment buildings or dwellings with no dedicated parking for home charging. Overcoming these and other barriers to achieve India's goal of a 30% market share for PEVs by 2030 will require multiple state and national policies.

Endnotes

1 Studies from IIT-Kanpur and The Energy and Resources Institute (TERI) identified the top sources of particulate matter in India's air. In decreasing order of contribution, they include industry, transport, dust, housing and agriculture stubble burning (Mohanty 2020; IANS 2020).

2 It is worth noting that a portion of oil imports is used for fuel exports.

3 Here, "local" refers to indigenous or domestically developed supply chains. It does not refer to the imported supply that is locally available.

4 Most studies focused on India take the form of either media or consultancy reports. To the best of our knowledge, this study is the first survey to focus on the entire Indian PEV ecosystem.

5 The use of a non-random sample to obtain survey data is a limitation of this study, as it may result in selection bias. The qualitative nature of this study also poses some shortcomings. Some respondents may have provided inaccurate but socially desirable responses. Others may have deliberately given certain answers to sway the study's findings in their sector's favor. We attempt to partly address these shortcomings by separately analyzing the responses from the for-profit and non-profit sectors.

6 We find that experts from the for-profit and non-profit sectors have statistically different beliefs regarding PEVs' expected annual share of sales in India by 2030. Specifically, the equality-of-medians test is rejected at the 10% significance level.

7 The overall expected market share is calculated by averaging each respondent's selected range. The overall minimum, maximum and average values are calculated by averaging the corresponding minimum, maximum or average values across all selected ranges.

8 When compared on a Likert-type scale, the importance levels of "financial incentives to reduce upfront costs" and the "higher upfront price of PEVs" are not statistically different at the 10% significance level.

9 These response distributions are statistically different from those of the other disablers and enablers. We perform equality-of-medians tests to compare the response distribution of "financial incentives to reduce upfront costs" to those of each other enabler. These tests reject the null hypothesis at the 5% significance level. Similarly, we perform equality-of-medians tests comparing the response distribution of the "higher upfront price of PEVs" to those of the other disablers. Again, the null hypotheses is rejected at the 5% significance level.

10 The equality-of-medians test comparing for-profit and non-profit experts' responses to "financial incentives to reduce upfront costs" rejects the null hypothesis at the 5% significance level.

11 The equality-of-medians test comparing for-profit and non-profit experts' responses to the "higher upfront price of PEVs" cannot reject the null hypothesis at the 10% significance level.

12 We perform equality-of-medians tests comparing the experts' responses to the disabler "lack of charging infrastructure" with their responses to each remaining disabler. These tests reject the null hypothesis at the 5% significance level. When we compare the experts' responses to the disabler "lack of PEV options" with their responses to each remaining disabler, we cannot reject the null hypothesis at the 10% significance level.

13 The equality-of-medians test comparing for-profit and non-profit experts' responses to the "lack of charging infrastructure" rejects the null hypothesis at the 5% significance level.

14 We perform an equality-of-medians test comparing the responses to the enablers "lower operation (fuel) and maintenance costs" and "reoccurring financial incentives from owing PEVs." This test cannot reject the null hypothesis at the 10% significance level. The equality-of-medians tests for the responses to each of these enablers and each remaining enabler reject the null hypothesis at the 1% significance level.

15 We perform an equality-of-medians test comparing for-profit and non-profit experts' responses to "lower operation (fuel) and maintenance costs" and "reoccurring financial incentives from owning PEVs." We cannot reject the null hypothesis at the 10% significance level.

16 We perform equality-of-medians tests comparing the response ratings of "lack of land availability and high land rent prices" with those of each other infrastructure barrier. The null hypotheses are rejected at the 5% significance level.

17 The equality-of-medians tests comparing the response ratings for pairs of these factors cannot reject the null hypotheses at the 10% significance level.

18 The equality-of-medians test comparing for-profit and non-profit experts' responses for each of these factors cannot reject the null hypothesis at the 10% significance level.

19 The equality-of-medians tests comparing the distributions of the responses for these factors cannot reject the null hypothesis at the 10% significance level. The response distributions for a PEV mandate and more credits for PEV sales in CAFE norms are not statistically different (at the 10% significance level) either.

20 Because the responses at the national and state levels are consistent, implementing a PEV mandate at the national level is sufficient.

21 The equality-of-medians test shows that the response ratings for these respective factors are not statistically different at the 10% significance level.

22 The equality-of-medians test comparing for-profit and non-profit experts' response ratings for this factor cannot reject the null hypothesis at the 10% significance level.

23 The equality-of-medians test comparing for-profit and non-profit experts' response ratings for these factors cannot reject the null hypothesis at the 10% significance level.

Endnotes

24 The equality-of-medians tests comparing the response ratings for these factors cannot reject the null hypothesis at the 10% significance level.

25 For battery manufacturing, “grants for research and development” was selected as the second-most important enabler, followed by “tax cut incentives.” However, the order of their importance based on the Likert-type scale responses is reversed.

26 The equality-of-medians tests comparing the response ratings for these respective factors cannot reject the null hypotheses at the 10% significance level.

27 The equality-of-medians test comparing the for-profit and non-profit experts’ responses for this factor rejects the null hypothesis at the 10% significance level.

28 The equality-of-medians test comparing the for-profit and non-profit experts’ responses for this factor cannot reject the null hypothesis at the 10 % significance level.

29 The equality-of-medians test comparing the response ratings for these two factors rejects the null hypothesis at the 10% significance level.

30 The equality-of-medians test comparing for-profit and non-profit experts’ responses regarding the extent of expected GHG emissions reductions rejects the null hypothesis at the 10% significance level.

31 Figure A1 in the appendix presents a brief timeline of central government policy initiatives.

32 The remaining 4% of the FAME II incentives are set aside for administrative expenditures, including publicity.

33 At the central level, three policy levers, namely PEV mandates, CAFE norms and bans on new ICEV sales, can be categorized as CAC policies. At the state level, CAC-type policies include PEV mandates, low/zero emission zones and vehicle license plate restrictions.

34 This target is met using the electric vehicle sales mandate policy lever in the EPS model. This particular policy option in the EPS enables PEVs to reach a fixed percentage of new passenger vehicle sales by a certain year (2030). The EPS assumes that the PEV market share increases linearly each year from now until 2030.

35 The corresponding reduction in crude oil imports is ~23.6 million barrels per year. For context, India’s total crude oil imports in 2030 are expected to be 3,992 million barrels per year based on the EPS’s BAU scenario.

36 It is worth noting that India levies custom duties of up to 40% on imported PEVs to promote domestic manufacturing (Ghosh and Bhaskar 2020).

References

Aasness, Marie Aarestrup, and James Odeck. 2015. "The Increase of Electric Vehicle Usage in Norway—Incentives and Adverse Effects." *European Transport Research Review* 7(4):34. doi: http://doi.org/10.1007/s12544-015-0182-4

Adepetu, Adedamola, and Srinivasan Keshav. 2017. "The Relative Importance of Price and Driving Range on Electric Vehicle Adoption: Los Angeles Case Study." *Transportation* 44(2):353–73. doi: http://doi.org/10.1007/s11116-015-9641-y

Albrahim, Mohammed, Ahmed Al Zahrani, Anvita Arora, Rubal Dua, Bassam Fattouh, and Adam Sieminski. 2019. "An Overview of Key Evolutions in the Light-Duty Vehicle Sector and Their Impact on Oil Demand." *Energy Transitions* 3(1):81–103. doi: http://doi.org/10.1007/s41825-019-00017-7

Alliance for an Energy Efficient Economy (AEEE). 2020. *Charging India's Two- and Three-Wheeler Transport*. Alliance for an Energy Efficient Economy. https://shaktifoundation.in/wp-content/uploads/2020/09/Full-Report_Charging-Indias-Two-Three-Wheeler-Transport.pdf

Axsen, Jonn, Joseph Bailey, and Marisol Andrea Castro. 2015. "Preference and Lifestyle Heterogeneity among Potential Plug-in Electric Vehicle Buyers." *Energy Economics* 50:190–201. doi: https://doi.org/10.1016/j.eneco.2015.05.003

Axsen, Jonn, Patrick Plötz, and Michael Wolinetz. 2020. "Crafting Strong, Integrated Policy Mixes for Deep CO_2 Mitigation in Road Transport." *Nature Climate Change* 10(9):809–18. doi: http://doi.org/10.1038/s41558-020-0877-y

Bansal, Prateek, and Kara M. Kockelman. 2017. "Indian Vehicle Ownership: Insights from Literature Review, Expert Interviews, and State-Level Model." Paper read at Journal of the Transportation Research Forum.

Bayer, Patrick, and Michaël Aklin. 2020. "The European Union Emissions Trading System Reduced CO_2 Emissions Despite Low Prices." *Proceedings of the National Academy of Sciences* 117(16):8804–12. doi: http://doi.org/10.1073/pnas.1918128117

BBC News. 2019. "India Turns to Electric Vehicles to Beat Pollution." *BBC News*, July 24. https://www.bbc.com/news/world-asia-india-48961525

Belzer, Richard. 2007. "New Motor Vehicle Fuel Economy Standards - Part 2: CAFE as Command-and-control Regulation." *Neutral Source*, July 24. http://neutralsource.org/archives/814

Berkeley, Nigel, David Jarvis, and Andrew Jones. 2018. "Analysing the Take up of Battery Electric Vehicles: An Investigation of Barriers amongst Drivers in the UK." *Transportation Research Part D: Transport and Environment* 63:466–81. doi: https://doi.org/10.1016/j.trd.2018.06.016

Bernard, Steven, and Amy Kazmin. 2018. "Dirty Air: How India Became the Most Polluted Country on Earth." *Financial Times*, December 11. https://ig.ft.com/india-pollution/

Bhalla, Pretty, Inass Salamah Ali, and Afroze Nazneen. 2018. "A Study of Consumer Perception and Purchase Intention of Electric Vehicles." *European Journal of Scientific Research* 149(4):362–8.

References

Bhaskar, Utpal. 2017. “India’s Electric Vehicle Drive: Challenges and Opportunities.” *LiveMint*, November 16. Accessed September 15, 2020. https://www.livemint.com/Industry/ji96zXi5dZz3L1XUSkiZxM/Indias-electric-vehicle-drive-Challenges-and-opportunities.html

Bjerkan, Kristin Ystmark, Tom E. Nørbech, and Marianne Elvsaas Nordtømme. 2016. “Incentives for Promoting Battery Electric Vehicle (BEV) Adoption in Norway.” *Transportation Research Part D: Transport and Environment* 43:169–80. doi: https://doi.org/10.1016/j.trd.2015.12.002

BP. 2016. “Back to the Future: Electric Vehicles and Oil Demand.” Accessed September 14, 2020. https://www.bp.com/en/global/corporate/news-and-insights/speeches/back-to-the-future-electric-vehicles-and-oil-demand.html

Bureau of Energy Efficiency (BEE). 2019. *Propelling Electric Vehicles in India: Technical Study of Electric Vehicles and Charging Infrastructure*. Bureau of Energy Efficiency. https://beeindia.gov.in/sites/default/files/2019%20-%20EY%20to%20BEE%20-%20Technical%20study%20on%20EVs%20%26%20Charging%20Infrastructure.pdf

Caperello, Nicolette, Kenneth Kurani, and Jennifer TyreeHageman. 2014. “I Am Not an Environmentalist Wacko! Getting from Early Plug-In Vehicle Owners to Potential Later Buyers.” *Transportation Research Board 2015 Annual Meeting*. Transportation Research Board.

Carley, Sanya, Saba Siddiki, and Sean Nicholson-Crotty. 2019. “Evolution of Plug-in Electric Vehicle Demand: Assessing Consumer Perceptions and Intent to Purchase over Time.” *Transportation Research Part D: Transport and Environment* 70:94–111. doi: https://doi.org/10.1016/j.trd.2019.04.002

Chaliawala, Nehal. 2020. “Government Allows Sale of Electric Vehicles without Batteries, Leaves Manufacturers Puzzled.” *The Economic Times*, August 12. Accessed September 20, 2020. https://economictimes.indiatimes.com/industry/auto/auto-news/government-allows-sale-of-electric-vehicles-without-batteries-leaves-manufacturers-puzzled/articleshow/77509605.cms

Choi, Dooyoung, and Kim K. P. Johnson. 2019. “Influences of Environmental and Hedonic Motivations on Intention to Purchase Green Products: An Extension of the Theory of Planned Behavior.” *Sustainable Production and Consumption* 18:145–55. doi: https://doi.org/10.1016/j.spc.2019.02.001

Council on Energy, Environment and Water (CEEW). 2018. *India’s Energy Transition: Subsidies for Fossil Fuels and Renewable Energy, 2018 Update*. International Institute for Sustainable Development. https://www.ceew.in/sites/default/files/IISD_CEEW_India_Energy_Transition_20Dec18.pdf

———. 2019. *India’s Electric Vehicle Transition: Impact on Auto Industry and Building the EV Ecosystem*. https://www.ceew.in/publications/india%E2%80%99s-electric-vehicle-transition

Cruze, Danny Cyril D. 2020. “Indian Govt to Allow Registration of Electric Vehicles without Batteries.” *LiveMint*, August 12. Accessed September 20, 2020. https://www.livemint.com/auto-news/indian-govt-to-allow-registration-of-electric-vehicles-without-batteries-11597243630452.html

de Haan, Peter, Michel G. Mueller, and Roland W. Scholz. 2009. “How Much Do Incentives Affect Car Purchase? Agent-Based Microsimulation of Consumer Choice of New Cars—Part II: Forecasting Effects of Feebates Based on Energy-Efficiency.” *Energy Policy* 37(3):1083–94. doi: https://doi.org/10.1016/j.enpol.2008.11.003

Deloitte. 2019. *Recharging India's Electric Vehicle Ambition by Electrifying Public Transport*. https://www2.deloitte.com/content/dam/Deloitte/in/Documents/public-sector/in-consulting-recharging-india-electic-vehicle-noexp.pdf

DeShazo, J. R. 2016. "Improving Incentives for Clean Vehicle Purchases in the United States: Challenges and Opportunities." *Review of Environmental Economics and Policy* 10(1):149–65. doi: http://doi.org/10.1093/reep/rev022

Dogra, Sarthak. 2019. "Green Number Plates Are Now Mandatory For All Electric Vehicles And It Is All For Good." *IndiaTimes*, May 1. Accessed September 15, 2020. https://www.indiatimes.com/auto/current/green-number-plates-are-now-mandatory-for-all-electric-vehicles-and-it-is-all-for-good-366403.html

Dombrowski, Uwe, and Christian Engel. 2013. After Sales Strategies for the Original Equipment Manufacturer of Electric Mobiles. In: Nee A., Song B., Ong SK. (eds) *Re-engineering Manufacturing for Sustainability*. Springer. https://link.springer.com/chapter/10.1007/978-981-4451-48-2_57

Dombrowski, Uwe, and Christian Engel. 2014. "Impact of Electric Mobility on the After Sales Service in the Automotive Industry." *Procedia* CIRP 16:152–7. doi: https://doi.org/10.1016/j.procir.2014.01.022

Dua, Rubal, and Kenneth White. 2020. "Understanding Latent Demand for Hybrid and Plug-In Electric Vehicles Using Large-Scale Longitudinal Survey Data of US New Vehicle Buyers." *Energy Efficiency* 13(6):1063–74. doi: http://doi.org/10.1007/s12053-020-09865-5

Dua, Rubal, Kenneth White, and Rebecca Lindland. 2019. "Understanding Potential for Battery Electric Vehicle Adoption Using Large-Scale Consumer Profile Data." *Energy Reports* 5:515–24. doi: https://doi.org/10.1016/j.egyr.2019.04.013

The Economic Times. 2019. "Can't Afford to Ban Vehicles Run on Fossil Fuel: Dharmendra Pradhan." *Economic Times*, July 17. Accessed September 15, 2020. https://economictimes.indiatimes.com/industry/energy/oil-gas/cant-afford-to-ban-vehicles-run-on-fossil-fuel-dharmendra-pradhan/articleshow/70253705.cms

Energy Innovation, World Resources Institute. 2020. "India Energy Policy Simulator." https://india.energypolicy.solutions/scenarios/home

Engel, Hauke, Russell Hensley, Stefan Knupfer, and Shivika Sahdev. 2018. *Charging Ahead: Electric-vehicle Infrastructure Demand.* https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.pdf

Ernst & Young. 2017. *Standing up India's EV Ecosystem - Who Will Drive the Charge*? https://www.ey.com/Publication/vwLUAssets/EY-standing-up-Indias-ev-ecosystem-who-will-drive-the-charge/$File/EY-standing-up-Indias-ev-ecosystem-who-will-drive-the-charge.pdf

ET Bureau. 2019. "Won't Ban Petrol, Diesel Vehicles, Says Nitin Gadkari." *The Economic Times*, July 16. https://economictimes.indiatimes.com/news/politics-and-nation/wont-ban-petrol-diesel-vehicles-says-nitin-gadkari/articleshow/70250904.cms

References

Franke, Thomas, Isabel Neumann, Franziska Bühler, Peter Cocron, and Josef F. Krems. 2012. "Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers." *Applied Psychology* 61(3):368–91. doi: http://doi.org/10.1111/j.1464-0597.2011.00474.x

Friedrich, Johannes, Mengpin Ge, and Andrew Pickens. 2017. *This Interactive Chart Explains World's Top 10 Emitters, and How They've Changed.* World Resources Institute. https://www.wri.org/blog/2017/04/interactive-chart-explains-worlds-top-10-emitters-and-how-theyve-changed

Gai, Yijun, Laura Minet, I. Daniel Posen, Audrey Smargiassi, Louis-François Tétreault, and Marianne Hatzopoulou. 2020. "Health and Climate Benefits of Electric Vehicle Deployment in the Greater Toronto and Hamilton Area." *Environmental Pollution* 265:114983. doi: https://doi.org/10.1016/j.envpol.2020.114983

Gallagher, Kelly Sims, Fang Zhang, Robbie Orvis, Jeffrey Rissman, and Qiang Liu. 2019. "Assessing the Policy Gaps for Achieving China's Climate Targets in the Paris Agreement." *Nature Communications* 10(1):1256. doi: http://doi.org/10.1038/s41467-019-09159-0

Ganguly, Shreya. 2019. "Govt Scraps Policy Which Subsidises EVs and Taxes Polluting Vehicles." *Inc42*, March 5. Accessed September 20, 2020. https://inc42.com/buzz/govt-scraps-policy-which-subsidises-evs-and-taxes-polluting-vehicles/

Ghosh, Malyaban. 2019. "Govt Steps on the Gas to Put India's EV Mission in Fast Lane." *LiveMint*, July 5. https://www.livemint.com/budget/news/govt-steps-on-the-gas-to-put-india-s-ev-mission-in-fast-lane-1562350841874.html

Ghosh, Malyaban, and Utpal Bhaskar. 2020. "Budget 2020 Proposes Hike in EV Import Duty to Promote Domestic Manufacturing." *LiveMint*, February 1. https://www.livemint.com/budget/news/budget-2020-proposes-hike-in-ev-import-duty-to-promote-domestic-manufacturing-11580557017403.html

Giansoldati, Marco, Adriana Monte, and Mariangela Scorrano. 2020. "Barriers to the Adoption of Electric Cars: Evidence from an Italian Survey." *Energy Policy* 146:111812. doi: https://doi.org/10.1016/j.enpol.2020.111812

Government of India. 2020. "MoRTH Allows Sale and Registration of Electric Vehicles Without Batteries." *Press Information Bureau*, August 12. Accessed September 20, 2020. https://pib.gov.in/PressReleseDetailm.aspx?PRID=1645394

Government of National Capital Territory of Delhi. 2020. *Delhi Electric Vehicles Policy*. https://transport.delhi.gov.in/sites/default/files/All-PDF/Delhi_Electric_Vehicles_Policy_2020.pdf

Greene, David L., Philip D. Patterson, Margaret Singh, and Jia Li. 2005. "Feebates, Rebates and Gas-guzzler Taxes: A Study of Incentives for Increased Fuel Economy." *Energy Policy* 33(6):757–75. doi: https://doi.org/10.1016/j.enpol.2003.10.003

Günther, H. O., Matthias Kannegiesser, and Niels Autenrieb. 2015. "The Role of Electric Vehicles for Supply Chain Sustainability in the Automotive Industry." *Journal of Cleaner Production* 90:220–33. doi: https://doi.org/10.1016/j.jclepro.2014.11.058

Guo, Chunlin, Jingjing Yang, and Lin Yang. 2018. "Planning of Electric Vehicle Charging Infrastructure for Urban Areas with Tight Land Supply." *Energies* 11(9):2314.

Guo, Zhaomiao, and Yan Zhou. 2019. "Residual Value Analysis of Plug-in Vehicles in the United States." *Energy Policy* 125:445–55. doi: https://doi.org/10.1016/j.enpol.2018.10.023

Hall, Dale, and Nic Lutsey. 2017. *Emerging Best Practices for Electric Vehicle Charging Infrastructure.* International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf

Hardman, Scott. 2019. "Understanding the Impact of Reoccurring and Non-financial Incentives on Plug-in Electric Vehicle Adoption – A Review." *Transportation Research Part A: Policy and Practice* 119:1–14. doi: https://doi.org/10.1016/j.tra.2018.11.002

Hardman, Scott, and Daniel Sperling. 2020. *EV Uptake in the Transport Fleet: Consumer Choice, Policy Incentives and Consumer-Centric Business Models*. *Oxford Energy Forum*, 122 https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/07/OEF122.pdf

He, Hui, Lingzhi Jin, Hongyang Cui, and Huan Zhou. 2018. *Assessment of Electric Car Promotion Policies in Chinese Cities*. International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/China_city_NEV_assessment_20181018.pdf

Higueras-Castillo, Elena, Sebastian Molinillo, J. Andres Coca-Stefaniak, and Francisco Liébana-Cabanillas. 2019. "Perceived Value and Customer Adoption of Electric and Hybrid Vehicles." *Sustainability* 11(18):4956. https://doi.org/10.3390/su11184956

Indian Council for Research on International Economic Relations (ICRIER). 2019. *Exploring Cost-reduction Strategies for Electric Vehicle (EV) Batteries*. https://shaktifoundation.in/wp-content/uploads/2020/02/Exploring-Cost-Reduction-Strategies-For-Electric-Vehicle-EV-Batteries.pdf

Indian Institute of Technology (IIT) Madras & World Resources Institute (WRI) India. 2019. *A Guidance Document on Accelerating Electric Mobility in India*. Shakti Sustainable Energy Foundation. https://wri-india.org/sites/default/files/Accelerating%20electric%20mobility%20in%20India_WRI%20India_CBEEVIITM.pdf

Indo-Asian News Service (IANS). 2020. "Stubble Burning Contributes Only 1% to Delhi's Pollution Menace." *IANS*, October 15. https://energy.economictimes.indiatimes.com/news/oil-and-gas/stubble-burning-contributes-only-1-to-delhis-pollution-menace/78672186

International Council on Clean Transportation (ICCT). 2019. *Electric Vehicle Guidebook for Indian States*. https://theicct.org/sites/default/files/publications/India_EV_State_Guidebook_20191007.pdf

———. 2020. I*mpacts of the Paris Low-emission Zone and Implications for Other Cities*. https://theicct.org/publications/true-paris-low-emission-zone

International Energy Agency (IEA). 2019a. *CO2 Emissions from Fuel Combustion 2019 Highlights*. https://webstore.iea.org/co2-emissions-from-fuel-combustion-2019-highlights

———. 2019b. *Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017*. https://www.iea.org/reports/fuel-economy-in-major-car-markets

International Renewable Energy Agency (IRENA). 2019. *Innovation Outlook: Smart Charging for Electric Vehicles*. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019.pdf

Jenn, Alan, Inês M. L. Azevedo, and Jeremy J. Michalek. 2016. "Alternative Fuel Vehicle Adoption Increases Fleet Gasoline Consumption and Greenhouse Gas Emissions under United States Corporate Average Fuel Economy Policy and Greenhouse Gas Emissions Standards." *Environmental Science & Technology* 50(5):2165–74. doi: http://doi.org/10.1021/acs.est.5b02842

Jin, Lingzhi, and Peter Slowik. 2017. *Literature Review of Electric Vehicle Consumer Awareness and Outreach Activities*. International Council on Clean Transportation. https://www.theicct.org/sites/default/files/publications/Consumer-EV-Awareness_ICCT_Working-Paper_23032017_vF.pdf

Kah, Marianne. 2018. *Electric Vehicles and Their Impact on Oil Demand: Why Forecasts Differ*. https://energypolicy.columbia.edu/sites/default/files/pictures/CGEP_Electric%20Vehicles%20and%20Their%20Impact%20on%20Oil%20Demand-Why%20Forecasts%20Differ.pdf

Kohli, Pranati Chestha. 2020. "Opportunities in EV Battery and Cell Manufacturing in India." *Invest India*, July 2. https://www.investindia.gov.in/team-india-blogs/opportunities-ev-battery-and-cell-manufacturing-india

Krupa, Joseph S., Donna M. Rizzo, Margaret J. Eppstein, D. Brad Lanute, Diann E. Gaalema, Kiran Lakkaraju, and Christina E. Warrender. 2014. "Analysis of a Consumer Survey on Plug-in Hybrid Electric Vehicles." *Transportation Research Part A: Policy and Practice* 64:14–31. doi: https://doi.org/10.1016/j.tra.2014.02.019

Li, Shanjun. 2018. "Better Lucky Than Rich? Welfare Analysis of Automobile Licence Allocations in Beijing and Shanghai." *The Review of Economic Studies* 85(4):2389–428. doi: http://doi.org/10.1093/restud/rdx067

Li, Zhe, and Minggao Ouyang. 2011. "The Pricing of Charging for Electric Vehicles in China—Dilemma and Solution." *Energy* 36 (9):5765–78. doi: https://doi.org/10.1016/j.energy.2011.05.046

Lieven, Theo. 2015. "Policy Measures to Promote Electric Mobility – A Global Perspective." *Transportation Research Part A: Policy and Practice* 82:78–93. doi: https://doi.org/10.1016/j.tra.2015.09.008

Lu, Chao, Ke Rong, Jianxin You, and Yongjiang Shi. 2014. "Business Ecosystem and Stakeholders' Role Transformation: Evidence from Chinese Emerging Electric Vehicle Industry." *Expert Systems with Applications* 41(10):4579–95. doi: https://doi.org/10.1016/j.eswa.2014.01.026

Luthra, Parikshit. 2018. "Niti Aayog Explores Feebate Model to Promote Electric Vehicles." *CNBC*, December 4. Accessed September 20, 2020. https://www.cnbctv18.com/auto/niti-aayog-explores-feebate-model-to-promote-electric-vehicles-1579681.htm

Lutsey, Nic. 2015. “Global Climate Change Mitigation Potential from a Transition to Electric Vehicles.” *The International Council on Clean Transportation* Working Paper 2015-5.

Lutsey, Nic, Mikhail Grant, Sandra Wappelhorst, and Huan Zhou. 2018. *Power Play: How Governments Are Spurring the Electric Vehicle Industry.* http://admin.indiaenvironmentportal.org.in/files/file/Power%20play.pdf

Ma, Shao-Chao, Ying Fan, and Lianyong Feng. 2017. “An Evaluation of Government Incentives for New Energy Vehicles in China Focusing on Vehicle Purchasing Restrictions.” *Energy Policy* 110:609–18. doi: https://doi.org/10.1016/j.enpol.2017.07.057

Melton, Noel, Jonn Axsen, and Barbar Moawad. 2020. “Which Plug-in Electric Vehicle Policies Are Best? A Multi-Criteria Evaluation Framework Applied to Canada.” *Energy Research & Social Science* 64:101411. doi: https://doi.org/10.1016/j.erss.2019.101411

Merz, Klaus-Dieter, and J. M. Stevenson. 1995. “Progress in the Design and Development of Improved Lead/Acid Batteries for Electric Buses and Vans.” *Journal of Power Sources* 53(2):317–21. doi: https://doi.org/10.1016/0378-7753(94)01992-5

Ministry of Heavy Industries & Public Enterprises. 2018. *National Auto Policy*. https://dhi.nic.in/writereaddata/UploadFile/National%20Automotive%20Policy%20Draft%20v2.pdf

———. 2019a. *Expression of Interest Inviting Proposals for Availing Incentives under FAME India Scheme Phase II For Deployment of EV Charging Infrastructure Within Cities*. https://dhi.nic.in/writereaddata/UploadFile/Revised-%20Expression%20of%20Interest.pdf

———. 2019b. *Scheme for Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME India Phase II)*. https://www.fame-india.gov.in/WriteReadData/userfiles/file/FAME-II%20Notification.pdf

Mohanty, Prasanna. 2020. “Rebooting Economy 39: Why Nobody Questions Industries Polluting Delhi Air the Most?” *Business Today*, October 22. https://www.businesstoday.in/opinion/columns/air-pollution-why-nobody-questions-industries-polluting-delhi-air-the-most-stubble-burning-dust-vehichles/story/419703.html

Münzel, Christiane, Patrick Plötz, Frances Sprei, and Till Gnann. 2019. “How Large is the Effect of Financial Incentives on Electric Vehicle Sales? – A Global Review and European Analysis.” *Energy Economics* 84:104493. doi: https://doi.org/10.1016/j.eneco.2019.104493

National Institution for Transforming India (NITI) Aayog. 2018. *Zero Emission Vehicles (ZEVs): Towards a Policy Framework*. New Delhi: NITI Aayog

National Institution for Transforming India (NITI) Aayog and Rocky Mountain Institute (RMI) India. 2017. *Valuing Society First: An Assessment of the Potential for a Feebate Policy in India*. New Delhi: NITI Aayog. https://niti.gov.in/writereaddata/files/document_publication/Valuing_Society_First_Feebates_Policy.pdf

———. 2019. *India’s Electric Mobility Transformation: Progress to Date and Future Opportunities*. New Delhi: NITI Aayog. https://rmi.org/wp-content/uploads/2019/04/rmi-niti-ev-report.pdf

References

Naumanen, Mika, Teuvo Uusitalo, Elina Huttunen-Saarivirta, and Robert van der Have. 2019. "Development Strategies for Heavy Duty Electric Battery Vehicles: Comparison between China, EU, Japan and USA." *Resources, Conservation and Recycling* 151:104413. doi: https://doi.org/10.1016/j.resconrec.2019.104413

Nicholas, Michael, and Dale Hall. 2018. *Lessons Learned on Early Electric Vehicle Fast-charging Deployments*. https://theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper_final.pdf

Noel, Lance, Gerardo Zarazua de Rubens, Johannes Kester, and Benjamin K. Sovacool. 2020. "Understanding the Socio-technical Nexus of Nordic Electric Vehicle (EV) Barriers: A Qualitative Discussion of Range, Price, Charging and Knowledge." *Energy Policy* 138:111292. doi: https://doi.org/10.1016/j.enpol.2020.111292

Ou, Shiqi, Xu Hao, Zhenhong Lin, Hewu Wang, Jessey Bouchard, Xin He, Steven Przesmitzki, Zhixin Wu, Jihu Zheng, Renzhi Lv, Liang Qi, and Tim J. LaClair. 2019. "Light-duty Plug-in Electric Vehicles in China: An Overview on the Market and Its Comparisons to the United States." *Renewable and Sustainable Energy Reviews* 112:747–61. doi: https://doi.org/10.1016/j.rser.2019.06.021

Parkin, Benjamin. 2019. "India's Mahindra Calls for Urgent Shift to Electric Vehicles." *Financial Times*. https://www.ft.com/content/9c460fcc-9f25-11e9-9c06-a4640c9feebb

Pereirinha, Paulo G., Manuela González, Isabel Carrilero, David Anseán, Jorge Alonso, and Juan C. Viera. 2018. "Main Trends and Challenges in Road Transportation Electrification." *Transportation Research Procedia* 33:235–42. doi: https://doi.org/10.1016/j.trpro.2018.10.096

Philip, Liljee. 2020. "Financing May Not Come Easy for Purchase of High-priced EVs." *Economic Times*, January 22. Accessed September 9, 2020. https://economictimes.indiatimes.com/industry/auto/auto-news/financing-may-not-come-easy-for-purchase-of-high-priced-evs/articleshow/73514294.cms?from=mdr

Phule, Unmesh. 2019. "India's Feebate Policy on Hold as EV Plans to be Delayed Till General Elections." *ReviewTech*, March 6. Accessed September 20, 2020. https://www.reviewtech.in/indias-feebate-policy-on-hold-as-ev-plans-to-be-delayed-till-general-elections/

Plötz, Patrick, Jonn Axsen, Simon A. Funke, and Till Gnann. 2019. "Designing Car Bans for Sustainable Transportation." *Nature Sustainability* 2(7):534–6. doi: https://doi.org/10.1038/s41893-019-0328-9

Rawat, Aman. 2020. "Govt to Set up 2,636 EV Charging Stations under FAME II." *Inc42*, January 3. https://inc42.com/buzz/govt-to-set-up-2636-ev-charging-stations-under-fame-ii/

Razeghi, Ghazal, Marc Carreras-Sospedra, Tim Brown, Jack Brouwer, Donald Dabdub, and Scott Samuelsen. 2016. "Episodic Air Quality Impacts of Plug-in Electric Vehicles." *Atmospheric Environment* 137:90–100. doi: https://doi.org/10.1016/j.atmosenv.2016.04.031

Schneidereit, Tina, Thomas Franke, Madlen Günther, and Josef F. Krems. 2015. "Does Range Matter? Exploring Perceptions of Electric Vehicles with and without a Range Extender among Potential Early Adopters in Germany." *Energy Research & Social Science* 8:198–206. doi: https://doi.org/10.1016/j.erss.2015.06.001

Schroeder, Andreas, and Thure Traber. 2012. “The Economics of Fast Charging Infrastructure for Electric Vehicles.” *Energy Policy* 43:136–44. doi: https://doi.org/10.1016/j.enpol.2011.12.041

Sen, Burak, Mehdi Noori, and Omer Tatari. 2017. “Will Corporate Average Fuel Economy (CAFE) Standard Help? Modeling CAFE’s Impact on Market Share of Electric Vehicles.” *Energy Policy* 109:279–87. doi: https://doi.org/10.1016/j.enpol.2017.07.008

Senecal, P. K., and Felix Leach. 2019. “Diversity in Transportation: Why a Mix of Propulsion Technologies Is the Way Forward for the Future Fleet.” *Results in Engineering* 4:100060. doi: https://doi.org/10.1016/j.rineng.2019.100060

Sharma, Nishant. 2020. “Industry Confused as India Takes the Battery out of EVs to Boost Demand.” *BloombergQuint*, September 15. Accessed September 20, 2020. https://www.bloombergquint.com/business/industry-confused-as-india-takes-the-battery-out-of-evs-to-boost-demand

Sharma, Yogima. 2020. “Niti Aayog Seeks Cabinet Nod for Battery Push.” *The Economic Times*, January 24. https://economictimes.indiatimes.com/news/economy/policy/niti-aayog-seeks-cabinet-nod-for-battery-push/articleshow/73569360.cms?from=mdr

Sheldon, Tamara L., and Rubal Dua. 2018. “Gasoline Savings from Clean Vehicle Adoption.” *Energy Policy* 120:418–24. doi: https://doi.org/10.1016/j.enpol.2018.05.057

———. 2019a. “Assessing the Effectiveness of California’s “Replace Your Ride.” *Energy Policy* 132:318–23. doi: https://doi.org/10.1016/j.enpol.2019.05.023

———. 2019b. “Measuring the Cost-effectiveness of Electric Vehicle Subsidies.” *Energy Economics* 84:104545. doi: https://doi.org/10.1016/j.eneco.2019.104545

———. 2020. “Effectiveness of China’s Plug-in Electric Vehicle Subsidy.” *Energy Economics* 88:104773. doi: https://doi.org/10.1016/j.eneco.2020.104773

Sierzchula, William, Sjoerd Bakker, Kees Maat, and Bert van Wee. 2014. “The Influence of Financial Incentives and Other Socio-economic Factors on Electric Vehicle Adoption.” *Energy Policy* 68:183–94. doi: https://doi.org/10.1016/j.enpol.2014.01.043

Skippon, Stephen, and Mike Garwood. 2011. “Responses to Battery Electric Vehicles: UK Consumer Attitudes and Attributions of Symbolic Meaning Following Direct Experience to Reduce Psychological Distance.” *Transportation Research Part D: Transport and Environment* 16(7):525–31. doi: https://doi.org/10.1016/j.trd.2011.05.005

Smart Electric Power Alliance (SEPA). 2019. *Preparing for an Electric Vehicle Future: How Utilities Can Succeed*. Smart Electric Power Alliance Electric Vehicle Working Group Distribution Planning Subcommittee. Accessed September 14, 2020. https://chanje.com/wp-content/uploads/2019/10/Preparing_for_an_Electric_Vehicle_Future_How_Utilities_Can_Succeed-SEPA-power-with-Dan-Wilson-lead-author-Oct-2019.pdf

Society of Indian Automobile Manufacturers (SIAM). 2019. *SIAM Annual Report* 2018-19. Society of Indian Automobile Manufacturers. http://www.siam.in/uploads/ar/21-21stAnnualReport2018-2019.pdf

References

Soni, Yatti. 2019. "India Will Not Ban Petrol and Diesel Engines, Assures Nitin Gadkari." *Inc42*, January 24. https://inc42.com/buzz/india-will-not-ban-petrol-and-diesel-engines-assures-nitin-gadkari/

Springer India New Delhi. 2012. "Beyond the Plug: Finding Value in the EV Charging Ecosystem." *Auto Tech Review* 1(11):18–23. doi: http://doi.org/10.1365/s40112-012-0170-1

Sullivan, Gail M., and Anthony R. Artino Jr. 2013. "Analyzing and Interpreting Data from Likert-type Scales." *Journal of Graduate Medical Education* 5(4):541–2.

The Energy and Resources Institute (TERI). 2019. *Faster Adoption of Electric Vehicles in India: Perspective of Consumers and Industry*. The Energy and Resources Institute. https://www.teriin.org/sites/default/files/2019-11/Faster%20adoption%20of%20electric%20vehicles%20in%20India.pdf

Tietge, Uwe, Peter Mock, Nicholas Lutsey, and Alex Campestrini. 2016. *Comparison of Leading Electric Vehicle Policy and Deployment in Europe*. International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/ICCT_EVpolicies-Europe-201605.pdf

Todd, Jennifer, Jess Chen, and Frankie Clogston. 2013. *Creating the Clean Energy Economy. Analysis of the Electric Vehicle Industry*. International Economic Development Council. http://large.stanford.edu/courses/2014/ph240/anderson-h1/docs/IEDC_Electric_Vehicle_Industry.pdf

Trivedi, Anjani. 2020. "The Latest Electric Car Hurdle: What If You Can't Resell It?" *Bloomberg*, July 29. Accessed September 14, 2020. https://www.bloomberg.com/opinion/articles/2020-07-29/better-batteries-drain-resale-value-from-today-s-electric-cars

Union Cabinet. 2019. *National Mission on Transformative Mobility and Battery Storage Approved by Cabinet*. Press Information Bureau, Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1567807#:~:text=The%20Mission%20will%20define%20the,employment%20generation%20in%20the%20country

U.K. Parliament. 2018. "Electric Vehicles: Driving the Transition." Accessed September 14, 2020. https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/38308.htm

U.S. Energy Information Administration (EIA). 2019. *What Countries Are the Top Producers and Consumers of Oil?* https://www.eia.gov/tools/faqs/faq.php?id=709&t=6

Vardhini C, Parvatha. 2019. "All You Wanted to Know about CAFE Regulations." *BusinessLine, The Hindu*, June 17. Accessed September 15, 2020. https://www.thehindubusinessline.com/opinion/columns/slate/all-you-wanted-to-know-about-cafe-regulations/article28022174.ece#:~:text=CAFE%20regulations%20in%20India%20came,113%20gm%20per%20km%20thereafter.&text=CAFE%20regulations%20assume%20importance%20in,footprint%20of%20the%20auto%20industry

Vassileva, Iana, and Javier Campillo. 2017. "Adoption Barriers for Electric Vehicles: Experiences from Early Adopters in Sweden." *Energy* 120:632–41. doi: https://doi.org/10.1016/j.energy.2016.11.119

Wangsness, Paal Brevik, Stef Proost, and Kenneth Løvold Rødseth. 2020. "Vehicle Choices and Urban Transport Externalities. Are Norwegian Policy Makers Getting It Right?" *Transportation Research Part D: Transport and Environment* 86:102384. doi: https://doi.org/10.1016/j.trd.2020.102384

Wu, Jingwen, Hua Liao, and Jin-Wei Wang. 2020. "Analysis of Consumer Attitudes Towards Autonomous, Connected, and Electric Vehicles: A Survey in China." *Research in Transportation Economics* 80:100828. doi: https://doi.org/10.1016/j.retrec.2020.100828

Wu, Tian, Bohan Zeng, Yali He, Xin Tian, and Xunmin Ou. 2017. "Sustainable Governance for the Opened Electric Vehicle Charging and Upgraded Facilities Market." *Sustainability* 9(11):2126. https://doi.org/10.3390/su9112126

Zarazua de Rubens, Gerardo, Lance Noel, Johannes Kester, and Benjamin K. Sovacool. 2020. "The Market Case for Electric Mobility: Investigating Electric Vehicle Business Models for Mass Adoption." *Energy* 194:116841. doi: https://doi.org/10.1016/j.energy.2019.116841

Zhang, Qi, Hailong Li, Lijing Zhu, Pietro Elia Campana, Huihui Lu, Fredrik Wallin, and Qie Sun. 2018. "Factors Influencing the Economics of Public Charging Infrastructures for EV – A Review." *Renewable and Sustainable Energy Reviews* 94:500–09. doi: https://doi.org/10.1016/j.rser.2018.06.022

Zheng, Jihu, Xin Sun, Lijie Jia, and Yan Zhou. 2020. "Electric Passenger Vehicles Sales and Carbon Dioxide Emission Reduction Potential in China's Leading Markets." *Journal of Cleaner Production* 243:118607. doi: https://doi.org/10.1016/j.jclepro.2019.118607

Appendix

Figure A1. Policy timeline for central government initiatives (Source: KAPSARC analysis).

2009

2010

- The Ministry of New and Renewable Energy (MNRE) launches the New Technology Programmes to promote battery-operated vehicles through R&D/pilot projects and awareness programs.
- The MNRE launches the Alternate Fuels for Surface Transportation Programme to support PEV sales.

2012

- The Ministry of Communications and Information Technology launches the Modified Special Incentive Package Scheme, an industrial subsidy scheme covering incentives for advanced storage batteries.

2013

- The National Electric Mobility Mission Plan (NEMMP) 2020 is launched by Ministry of Heavy Industries & Public Enterprises (MoHIPE) with the aim of achieving national fuel security by promoting PEVs. The mission aims to achieve sales of 6-7 million units of PEVs by 2020.

2014

- The Ministry of Urban Development launches the National Urban Transport Policy to plan a roadmap for sustainable mobility.
- The MoRTH launches the Deendayal electric rickshaw scheme to replace conventional rickshaws with electric three-wheelers.

2015

- Phase I of the FAME scheme is launched by MoHIPE as part of NEMMP 2020 to incentivize the production and promotion of PEVs.

2016

- The Automotive Mission Plan 2026 is drafted by MoHIPE with the aim of making the Indian automotive industry a global leader. This policy emphasizes incentives for manufacturing PEVs and a sufficient number of charging stations for PEVs.

2017

- The Urban Green Mobility Scheme is launched by the Ministry of Housing and Urban Affairs (MoHUA) to promote alternate fuels and electric mobility for a better environment.

2018

- The national E- mobility program is launched by the Ministry of Power (MoP) with the aim of providing thrust to the development of a PEV ecosystem.
- The MoP issues a notification clarifying that charging electric vehicles is a service rather than a sale of electricity.
- The Department for Promotion of Industry and Internal Trade provides market opportunities for Indian startups through the Integrate to Innovate program.
- The MoP develops guidelines to set up private/public charging stations.
- The MoRTH amends the Central Motor Vehicles Rules by allowing drivers aged 16-18 to obtain licenses for electric scooters with a maximum restricted speed of 70 km/hour.

2019

- FAME phase 2 is launched by NITI Aayog, providing demand-side incentives for PEVs. The scheme also proposes to install 2,700 charging stations.
- The National Mission on Transformative Mobility and Battery Storage is launched by NITI Aayog. The mission aims to recommend policy guidelines to formulate and launch a PMP.
- The Central Electricity Authority amends its technical standards for the connectivity of the distributed generation resources to accommodate provisions for electric charging infrastructure.
- MoHUA amends its Urban Regional Development Plans Formulation and Implementation Guidelines of 2014 by adding guidelines for charging infrastructure standards.
- The National Policy on Electronics is launched by the Ministry of Electronics and Information Technology to incentivize and provide special support for the manufacture of core electronic components, including lithium ion batteries.

2020

Notes

Notes

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Rubal is a research fellow at KAPSARC focused on understanding consumer decision-making, in particular, consumer choice of energy-efficient technologies and mobility options under alternative technology and policy scenarios. Before joining KAPSARC, Rubal gained a Ph.D. at KAUST designing advanced carbon materials for energy and environmental applications, with a particular focus on energy storage, carbon capture, waste-water treatment, and hydrogen generation via solar water splitting. Prior to that, he worked at the University of Pennsylvania on a semiconductor industry-funded project, developing a continuum modeling framework for simulating the physics of micro defect formation in silicon crystals.

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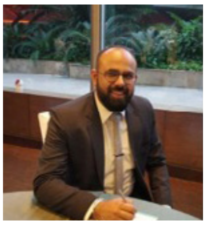

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About the Project

Promoting the adoption of energy-efficient vehicles has become a key policy imperative in both developed and developing countries. Understanding the impacts of various factors on adoption rates forms the backbone of KAPSARC's efforts in the light-duty vehicle demand field. These factors include (i) consumer-related factors – demographics, behavioral, and psychographics; (ii) regulatory factors – policies, incentives, rebates, and perks; and (iii) geo-temporal factors – weather, infrastructure and network effects. Our team is currently developing models at different levels: micro-level models using large-scale data comprising new car buyers' profiles, and macro-level models using aggregated adoption data to understand and project the effects of various factors that affect the adoption rate of energy-efficient vehicles.

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