Economic Advisory Council
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Igniting the Bright Spark

Through the Looking Glass on Electric Mobility in India

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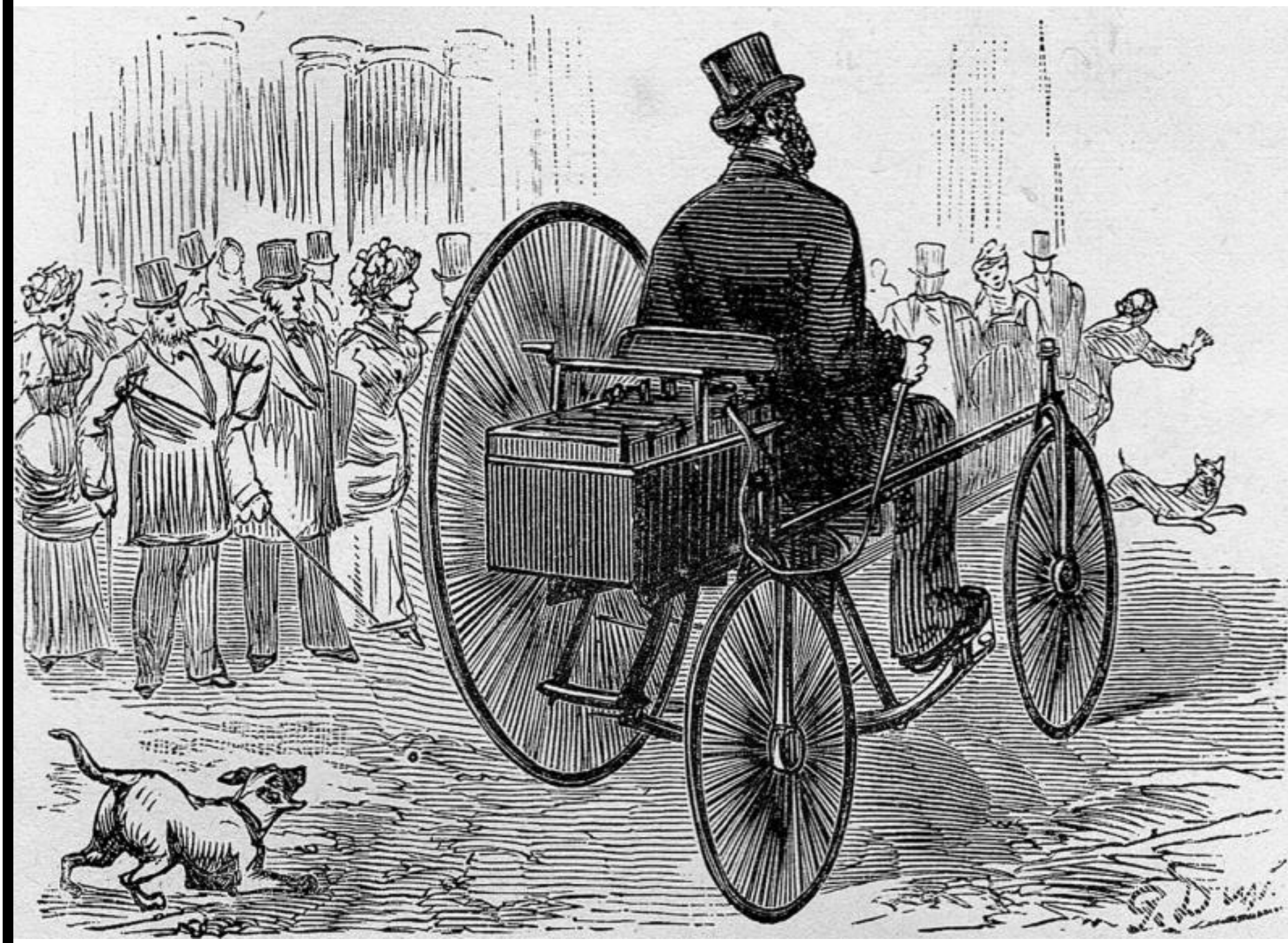

Bibek Debroy & Devi Prasad Misra

March, 2024

The artwork depicted above is *Gustave Trouvé's* Tricycle (1881), often regarded as the world's first electric vehicle [*Wikimedia Commons*]

Igniting the Bright Spark

Through the Looking Glass on Electric Mobility in India

By Bibek Debroy & Devi Prasad Misra[1]
March, 2024

Abstract

Compulsions of climate change commitments, caprices in oil prices coupled with a rapid acceleration of battery technologies have together led to a sharp increase in electric mobility worldwide. In the Indian context, a slew of measures – on the demand side as well as on the supply side have been announced from time to time. However, the results have been mixed.

While the sale and adoption of battery-electric two wheelers has significantly improved, especially in the last two years, however the adoption of electric vehicles particularly in the Light Motor Vehicles (LMV) segment continues to be low.

This study is an attempt to understand the reasons as to why the adoption of electric vehicles (EVs) in this category continues to be sluggish and possible measures that could be employed to enhance the penetration of EVs.

Further, in order to better understand the interplay between introduction of various measures for enhancing adoption of EVs and the impact of changes in macroeconomic indicators, a macro-econometric model, based on large economic datasets including national income, demographics etc. is used to forecast the impact of various policy interventions.

The Present State of Play

The total number of vehicles in India (as on August, 2022) stood at 28.37 Crore[2]. A fuel wise and category wise breakup is as under [Table 1]:

[1] Bibek Debroy is Chairman, Economic Advisory Council to the Prime Minister and Devi Prasad Misra, an officer of the Indian Revenue Service (Customs & Indirect Taxes) is Director, Economic Advisory Council to the Prime Minister

[2] Lok Sabha, Unstarred Question No. 3040 answered On 04th August, 2022 on Life Span of Vehicles

Table 1: Fuel wise, category wise distribution of total vehicles registered [as on August, 2022]

Fuel	Two Wheelers	Four [and four+] Wheelers	Total
Diesel	1,29,537	3,87,94,749	3,89,24,286
Petrol	21,18,61,387	3,01,93,332	24,20,54,719
Electric	5,44,643	54,252	5,98,895
Others	2,95,245	18,47,539	21,42,784
Grand Total	21,28,30,812	7,08,89,872	**28,37,20,684**

While, the no. of EVs as a percentage of total vehicles in the country stood at 0.21%, EV four-wheelers as a percentage of the total four wheelers amounted to only 0.08%. Any which way we look, the penetration of EVs in India remains low.

It is instructive to further examine the trends in vehicle registration in India. As per data from the Ministry of Road Transport & Highways[3] (MoRTH), the total number of vehicles registered in the year 2012-2013 was 1,75,61,196. This increased to 2,23,12,223 in 2022-23. A vehicle category wise distribution of the total vehicles registered in 2012-13 and in 2022-23 is as under [Table 1A].

Two wheelers and LMVs are the primary constituents of the total sales figures. It may be seen that the annual number of vehicles registered saw an increase of 27% in the period 2012-13 to 2022-23; a sizeable part of this increase came from the Light Motor Vehicle (LMV) segment which witnessed a 48% increase in absolute numbers.

Percentage contribution of LMVs to the total number of registered vehicles vis-à-vis the contribution of two wheelers has also shown an increasing trend. This is perhaps indicative of rising incomes, enhanced urbanization and higher rates of workforce participation[4].

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[3] https://vahan.parivahan.gov.in/vahan4dashboard/vahan/view/reportview.xhtml

[4] Shirgaokar, M. (2012). The Rapid Rise of Middle-Class Vehicle Ownership in Mumbai. UC Berkeley; https://escholarship.org/uc/item/84v2140d

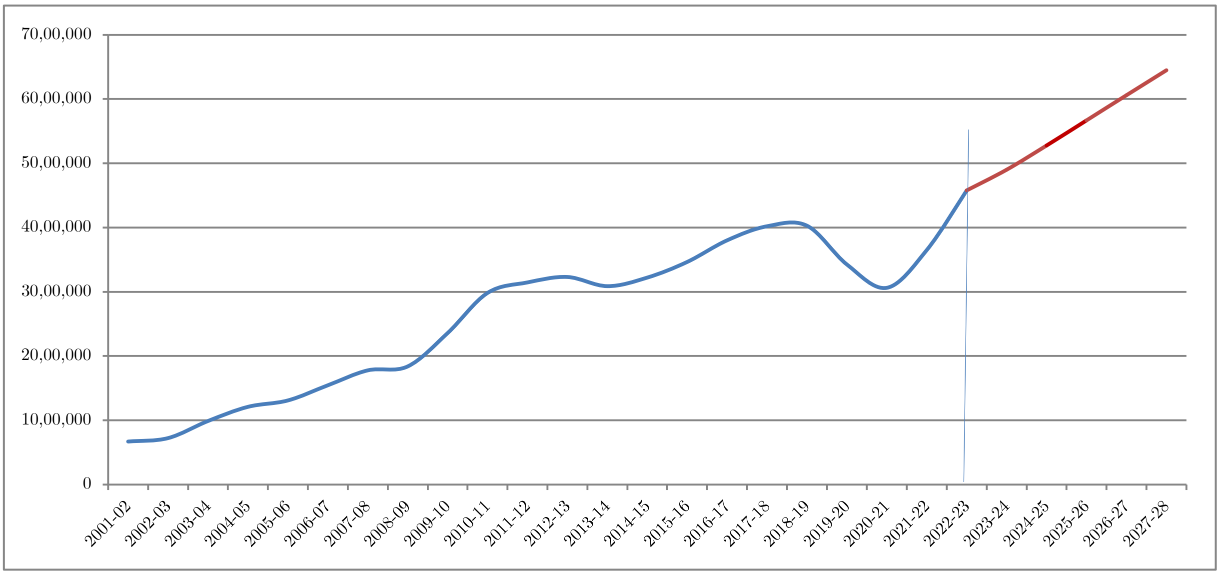
Table 1A: Category wise distribution of total vehicles registered [2012-13 and 2022-23]

	2012-13		2022-23	
Vehicle Category	**Total Nos.**	**Vehicle Type as % of Total**	**Total Nos.**	**Vehicle Type as % of Total**
Two Wheeler (NT)	1,30,07,268	74.07	1,60,04,448	71.73
Light Motor Vehicle	28,75,594	16.37	42,57,347	19.08
Light Goods Vehicle	5,57,550	3.17	6,14,179	2.75
Three Wheeler (T)	4,21,908	2.40	7,53,188	3.38
Light Passenger Vehicle	2,45,555	1.40	1,91,185	0.86
Heavy Goods Vehicle	2,32,567	1.32	2,81,655	1.26
Three Wheeler (NT)	57,955	0.33	25,272	0.11
Others	162799.00	0.93	184949	0.83
Total	**17561196**	**100**	**22312223**	**100**

NT: Non- Transport; T: Transport [Passenger/Good]

Interestingly, looking at the time series trends of production of passenger vehicles and projecting for the near future, we can see that annual passenger vehicle (LMV) production is likely to grow by about 71% from ~45 lakh in 2022-23 to ~65 lakh by 2027-28 [Figure 1][5]. It may be noted that the above figures are of production [including domestic sales and exports] and would differ from the figures of registration above [Table 1A].

Fig. 1: Annual Production of Passenger Vehicles (LMV); Projections upto 2027-28



This rise in vehicle ownership is bound to have an impact on the demand for fuel and on tail-pipe emissions. According to an analysis done by the Petroleum

[5] CMIE Industry Outlook; https://industryoutlook.cmie.com/kommon/bin/

Planning & Analysis Cell (PPAC) of the Ministry of Petroleum & Natural Gas (MoPNG)[6], four wheelers consumed 35.84% of the total Motor Spirit (Petrol) consumed in the country whereas 61.42% was consumed by two wheelers and 2.35% of the total by three wheelers.

Given that the total consumption of Motor Spirit (MS) in the year 2022-23 was estimated as being 35 Million Metric Tonnes (MMT)[7], it is estimated that four wheelers consumed 12.54 MMT of Motor Spirit. It is in this context that, EVs have been seen as an important tool for reducing dependence on fossil fuels as well as aiding in reduction of pollution[8].

This is on account of both the intrinsic energy efficiencies of an electric motor[9] as well as the dispersion of sources of power generation. It is in this background that with a view to encourage Electric Mobility, the National Mission on Electric Mobility was launched in 2011[10].

Further, an examination of the impact on the demand for electricity that greater adoption of Electric Vehicles (EVs) is likely to result in is an addendum to this paper.

From Vroom to Zoom?

A number of measures have been introduced for the promotion of EVs - FAME Scheme, 2015; FAME II Scheme, 2019; Production Linked Incentive (PLI) scheme for Automobile and Auto Components, 2021; lower rates of taxation etc. In addition a number of states have also introduced measures to encourage adoption of EVs[11].

As a result, there has been an increase in the number of EVs on the roads. This has been particularly sharp for the Two Wheelers (Non Transport) and slightly less for Three Wheelers (Transport) [Figure 2][12].

[6] https://pib.gov.in/newsite/printrelease.aspx?relid=102799

[7] https://ppac.gov.in/uploads/rep_studies/1689760261_PPAC_READY%20RECKONER-FY2022-23_web_compressed-compressed-min_compressed.pdf

[8] Public Health and Climate Benefits and Trade-Offs of U.S. Vehicle Electrification; https://doi.org/10.1029/2020GH000275

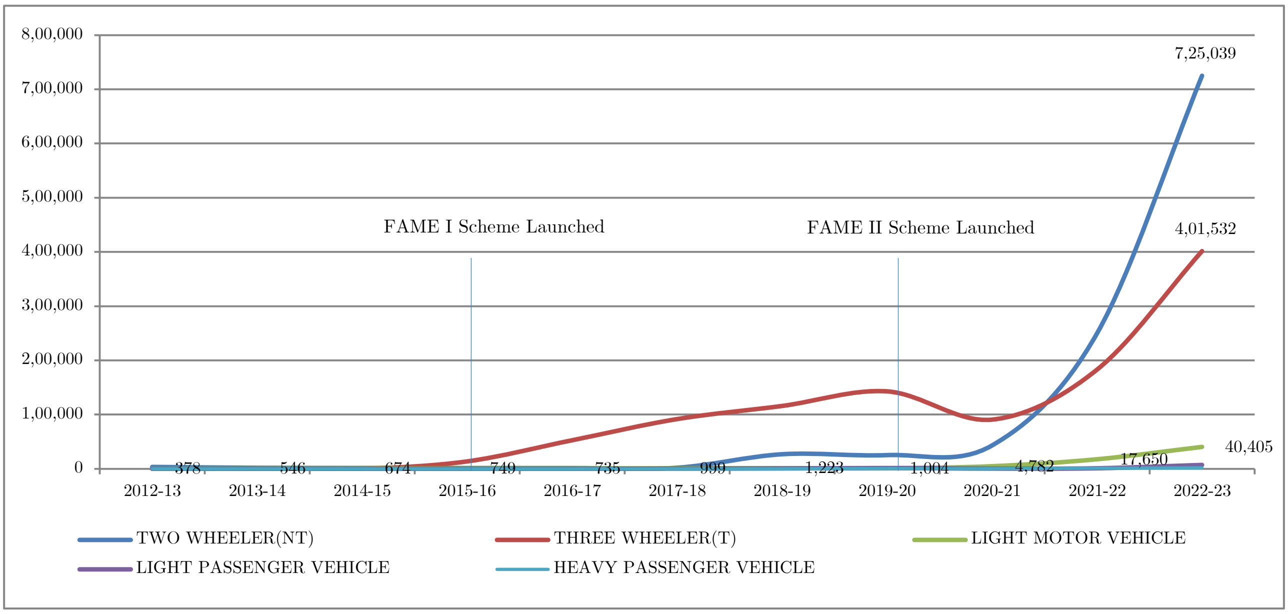
[9] Comparison of the Overall Energy Efficiency for ICE Vehicles and EVs [ALBATAYNEH1, N. ASSAF, ALTERMAN, JARADAT; 2020]

[10] https://fame2.heavyindustries.gov.in/content/english/15_1_FAMEI.aspx

[11] Twenty Sixth Report Committee On Estimates (2022-23) (Seventeenth Lok Sabha); Ministry Of Heavy Industries

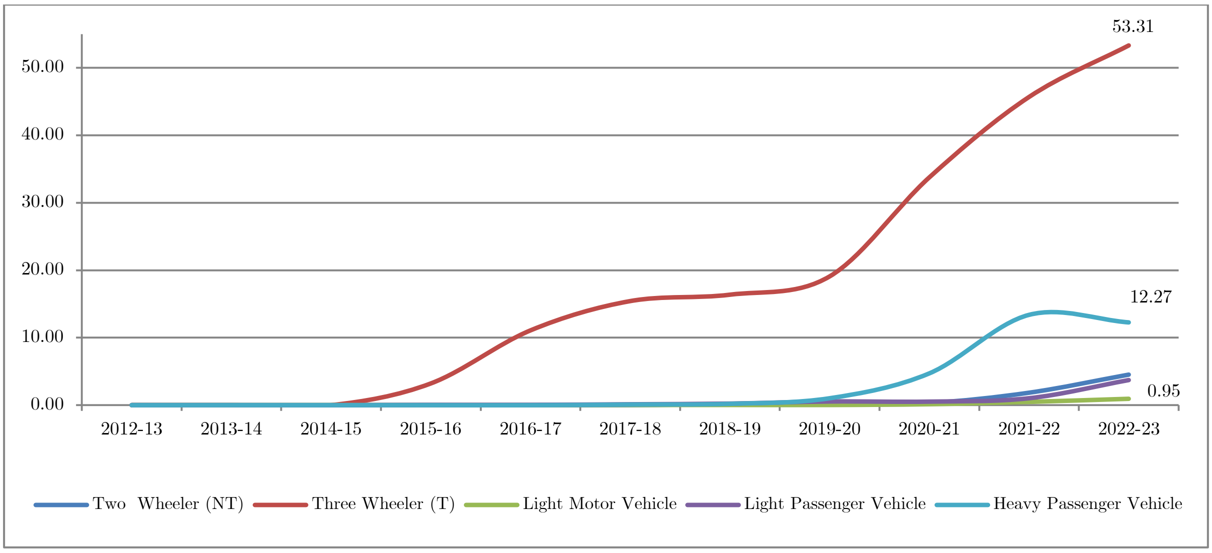
[12] https://vahan.parivahan.gov.in/vahan4dashboard/vahan/view/reportview.xhtml

Fig. 2: Yearwise no. of EVs registered [2012-13 to 2022-23; selected categories]



As a percentage of total registrations, EVs constituted 53.31% of the total three wheelers registered in 2022-23; whereas only 0.95% of LMVs were EVs. Therefore it may be seen that both in absolute numbers as well as in percentage terms, adoption of LMV EVs has remained sluggish.

Fig. 3: Yearwise EVs registered as a percentage of total registrations
[2012-13 to 2022-23; selected categories]



EV Demand: Stuck in second gear

While there is much to examine in the EV space, both internationally as well as closer home, however the thrust of the instant paper is to examine the reasons why the growth in EVs, particularly in the LMV segment in India has been sluggish and what could be the possible policy responses for the same.

A review of studies[13] and reports[14] on the subject indicate the following main reasons for EV adoption hesitancy:

- High upfront cost/Total Cost of Ownership
- Range Anxiety
- Logistical Reasons such as lack of model options, unknown resale value, early stage of EV technology development etc.

We take up each of the issues individually for further examination.

Show me the Money: High upfront cost/Total Cost of ownership

While admittedly, at present, the upfront cost of EVs might be higher to begin with, however the running costs are significantly lower given the price differential of electricity over diesel/gasoline. In addition, electric powered vehicles are found be more than 4 times more energy efficient than their fossil fuel powered counterparts[15]. Further, the fact there are fewer moving parts in the vehicle significantly reduces the cost of maintenance, lubricants etc.

In order to model for the total cost of ownership of an electric vehicle vis-à-vis one powered by gasoline/diesel, an exercise was carried out using the *Total Cost of Ownership* (TCO) tool of the International Energy Agency[16] (IEA). The TCO tool combines data on purchase costs, regular expenses such as fuelling/charging, maintenance as well as financing costs.

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[13] Can gain motivation induce Indians to adopt electric vehicles? Application of an extended theory of Planned Behavior to map EV adoption intention (Deka, Dutta, Yazdanpanah, Komendantova, 2023); https://doi.org/10.1016/j.enpol.2023.113724

[14] Twenty Sixth Report Committee On Estimates (2022-23) (Seventeenth Lok Sabha); Ministry Of Heavy Industries

[15] https://www.tesla.com/ns_videos/Tesla-Master-Plan-Part-3.pdf, Pg. 5

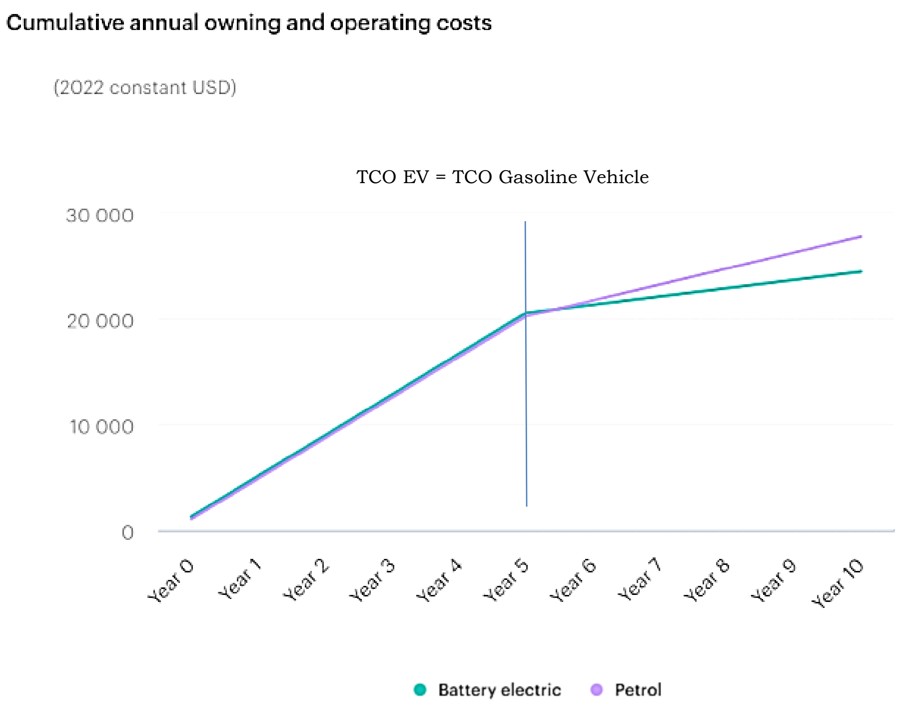
[16] https://www.iea.org/

The annual mileage is taken as 12,199 ± 435 km. This is as per a study carried out by the United Nations Environment Program (UNEP) and the Indian Institute of Technology, Delhi (IITD)[17].

The model is premised on the following assumptions - the cost of the EV as being USD 12,326 [Rs. 10,26,947] and cost of the closest Petrol equivalent as being USD 9,832 [Rs. 8,20,000]; cost of electricity at 0.07 USD/kWh [Rs. 5.83/kWh] and cost of gasoline at USD 1.16/L [Rs. 96.65/L].

Using these and other values we estimate for the difference in the cost of ownership. The results are depicted in Figure 4/4A.

Fig. 4 Cost of Ownership for Electric and a Gasoline Vehicle [Small Car]

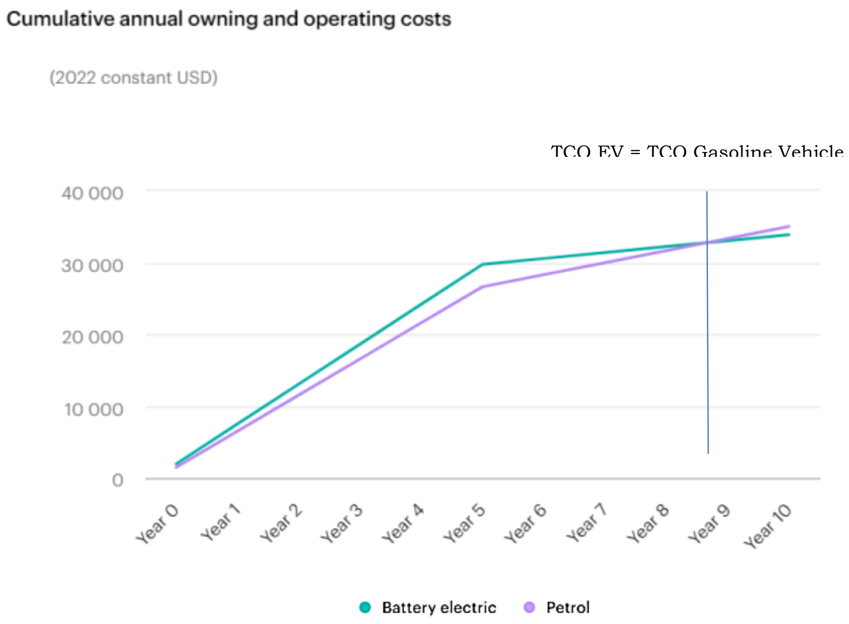


Small Car is defined as a A or B Segment Vehicle [eg. Hatchbacks][18]

[17] Promoting low carbon transport in India; Study by UNEP & IIT Delhi; https://wedocs.unep.org/bitstream/handle/20.500.11822/17003/1/Promoting_Low_Carbon_Transport_in_India_Project_Brochure.pdf

[18] European Commission Vehicle Classification [https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types]; World Forum for Harmonization of Vehicle Regulations [United Nations Economic and Social Council Resolution ECE/TRANS/WP.29/78/Rev.6]

Fig. 4A Cost of Ownership for Electric and a Gasoline Vehicle [Mid-Size Car]



Mid-Size Car is defined as a C or D Segment Vehicle [eg. Family Sedans][19]

From the above, it is evident that for small cars, the cost of ownership is in favour of electric vehicles from the fifth year onwards whereas for mid-size vehicles the equation turns favourable for electric vehicles from the 9th year onwards. While the upfront costs for an EV might be higher, however given that multiple financing options are available, the relatively higher upfront costs would be spread across the loan tenure.

Footsteps into the Unknown: Anxiety regarding range in EVs

Range anxiety is the fear that the vehicle has insufficient fuel to cover the road distance needed to reach the intended destination and would lead to the vehicle's occupants being left stranded mid-way[20]. The term, typically used for electric cars, is considered to be one of the major psychological barriers to large-scale public adoption of electric cars[21] and is so pervasive that in 2010, a US auto giant, even filed to trademark the term[22].

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19 IEA Global EV Outlook 2022 https://iea.blob.core.windows.net/assets/e0d2081d-487d-4818-8c59-69b638969f9e/GlobalElectricVehicleOutlook2022.pdf

20 Backstrom, Michael (2009). "Comments of Southern California Edison Company on the California Public Utilities Commission Staff's White Paper, Light-Duty V"

21 Eberle, Ulrich; von Helmolt, Rittmar (2010-05-14). "Sustainable transportation based on electric vehicle concepts: a brief overview". Royal Society of Chemistry.

22 https://jalopnik.com/how-gm-will-use-fear-to-sell-you-a-chevy-volt-5626306

The highest selling EV in India features a range of over 300 kms per charge [10% to 80% charge is advertised as taking about 1.5 hours]. This is typically the range of most EVs in the market today.

As per a study conducted by the School of Planning & Architecture, New Delhi, the average trip length in Delhi was quantified as being 10.2 kms in 2007[23]. Doubling that to account for to and fro makes it about 20.4 kms/day. However, given that the figures are a bit dated we make use of the UNEP and IIT Delhi study[24] mentioned above to arrive at a figure of the average daily use of a car at 33.42 ± 1.19 kms.

For a typical use case the range being offered in EVs presently on the market should suffice. Typically, the calculation would hold even if we factor commercial use, in which case the fuel savings would be substantial to justify investment in an EV.

As of March, 2023, there were 6586 publically accessible EV Charging Stations in the country. Further, there were 419 Public EV Charging Stations along highways[25]. A visualization of the statewise distribution of Public EV Charging Stations is at Figure 4B.

While we examine the spread of the public charging network it is also instructive to take a look at the statewise distribution of EVs in India. The total stock of EVs in India as on 3rd of August, 2023 stood at 28,30,565[26]. A visualization of the statewise distribution of the total EV stock is at Figure 4C[27].

It may be kept in view that the figures are for the total EV stock i.e. all types of EVs – two wheelers, three wheelers, LMVs etc. are included.

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23 Rapid Assessment of Travel Patterns In Delhi - Horizon Year 2030 & 2050, SPA, Gupta; Dameniya (2017)

24 Promoting low carbon transport in India; Study by UNEP & IIT Delhi; https://wedocs.unep.org/bitstream/handle/20.500.11822/17003/1/Promoting_Low_Carbon_Transport_in_India_Project_Brochure.pdf

25 Rajya Sabha; Unstarred Question No. 2837; Answered On 24.03.2023

26 Ministry of Road Transport & Highways Press Release dated 10th August, 2023; https://pib.gov.in/PressReleasePage.aspx?PRID=1947389

27 Lok Sabha; Unstarred Question No. 3482; Answered On 10th August, 2023

Fig. 4B: Statewise distribution of Public EV Charging Stations

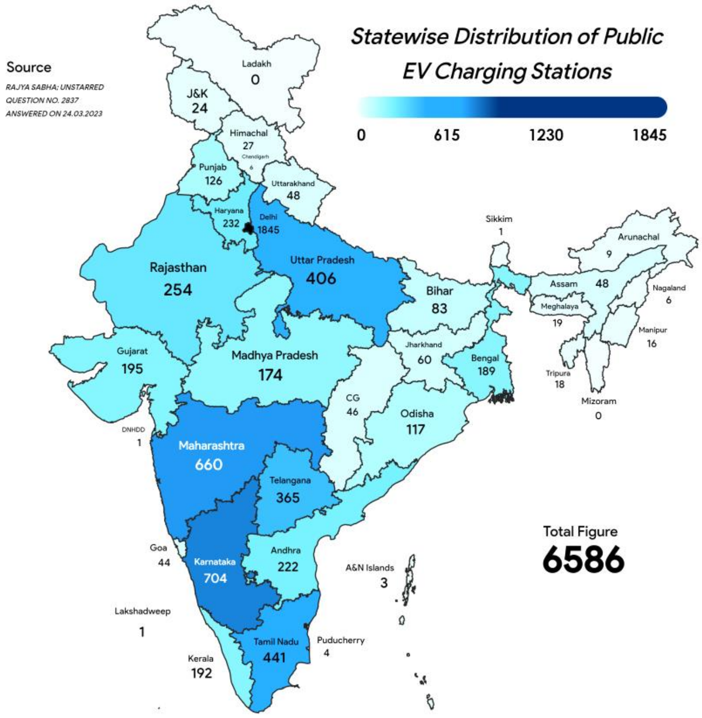
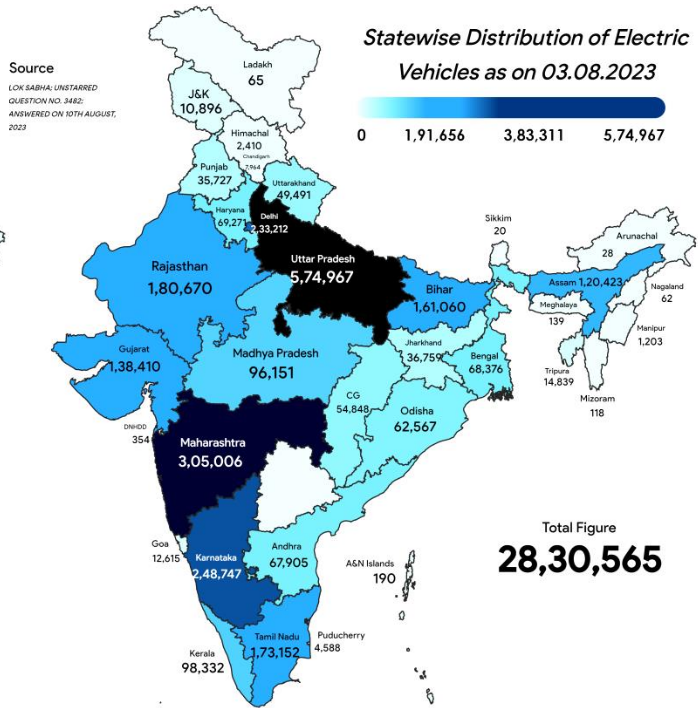


Fig. 4C: Statewise distribution of EVs as on 03.08.23



This is in addition to the private/captive EV chargers[28]. There are more on the way with many fuel marketing PSUs announcing plans to provide EV charging facilities at petrol pumps[29].

Given the rapid development in battery technology and reducing charging times coupled with an increase in the EV charging infrastructure in the country, the anxiety of being left stranded seems rather unlikely.

However, in the immediate term the need would be to rapidly scale up our Public EV Charging network. A number of incentives and enabling provisions have already been announced to that end. Given their reach, numbers and ready availability of space perhaps existing petrol pumps may be ideal for this.

[28] https://pib.gov.in/PressReleasePage.aspx?PRID=1910392

[29] https://timesofindia.indiatimes.com/auto/news/indian-oil-hpcl-bpcl-promote-e-mobility-nearly-9000-petrol-pumps-now-offer-ev-charging-stations/articleshow/101385395.cms?from=mdr

The Nuts & Bolts: Logistical Reasons

Reasons such as the lack of diversity in the model offerings, EV technology being at an early stage of development etc. are all factors which can get addressed by market forces once the adoption of EVs starts increasing.

This was seen in China where as recently as 2013, less than 1% of LMVs sold were EVs. At present over 30% of new LMVs sold are EVs[30]. This rapid increase in the numbers of EV also led to an increase in the number of manufacturers, variety of models, network of charging stations etc.

China has pushed for expansion of its EV manufacturing capabilities from the early 2000s. It is estimated that between 2009 and 2022, the Chinese government poured over US$29 billion into subsidies and tax breaks for Chinese EV manufacturers[31].

From 2018, China introduced a mandate for Electric Vehicles, called the New Energy Vehicle (NEV) Mandate Policy[32]. The policy, specifies NEV credit targets for two years: 10% of the conventional passenger vehicle market in 2019 and 12% in 2020. Many Chinese States have also partnered closely with EV manufactures for procurement of EVs for public transport[33].

In such cases, typically early adoption of EVs has come from either state mandates or from state subsidies. We examine this issue later in this paper.

Stepping on the gas: Encouraging adoption of EVs

India is dependent on oil imports. We spent USD 144.2 billion in FY 2022–23 on the net import of oil and gas. This is up from USD 113.4 billion in FY 2021-22[34]. High crude oil prices in the international market also have an adverse impact on country's economy. Further, we are committed to Net-Zero carbon emissions by 2070 and to reduce our total projected carbon emissions by one billion tonnes by 2030[35].

30 Jose, Pontes (22 January 2022), CleanTechnica; https://en.wikipedia.org/wiki/Electric_car_use_by_country

31 MIT Technology Review [February, 2023]; https://www.technologyreview.com/2023/02/21/1068880/how-did-china-dominate-electric-cars-policy/

32 http://www.miit.gov.cn/n1146295/n1146557/n1146624/c5824932/content.html (in Chinese)

33 https://www.technologyreview.com/2023/02/21/1068880/how-did-china-dominate-electric-cars-policy/

34 PPAC Monthly Ready Reckoner; https://ppac.gov.in/uploads/whatsnew/1695125647_MRR_August23_web%20upload.pdf

35 Twenty Sixth Report Committee On Estimates (2022-23) (Seventeenth Lok Sabha); Ministry Of Heavy Industries

That being so, faster adoption of Electric vehicles will not only bring down the import bill but would also have a significant impact on emissions.

India represents the fifth largest automobile market in the world. We already are the world's largest 3-Wheeler, 2nd largest 2-Wheeler and 3rd largest manufacturer of passenger cars[36]. As the world moves towards greater adoption of EVs, having a robust EV manufacturing capability would allow us to service this demand.

The development and manufacture of an Electric Vehicle is relatively simpler than that of an Internal Combustion Engine (ICE) powered vehicle and typically involves comparatively lesser initial investment. In fact, some of the fastest growing brands of EVs are new players in their respective market – be it Tesla or the Chinese EVs manufacturers in markets outside of China. This phenomenon is seen in our domestic electric two wheelers market as well, where the biggest players are all new to the market.

It is in this context that perhaps, existing auto manufacturers with established delivery, marketing and maintenance networks might require an incentive/mandate/nudge to produce and market EVs.

i. *Introducing tradable production mandates*

Measures such as the introduction of a mandate specifying a certain percentage of sales of each auto company to be EVs have been seen as likely to accelerate the adoption of EVs. Such mandates have been introduced by many jurisdictions such as a number of states of the US[37], Canada[38] and China[39].

To begin with the mandate could specify that be a small percentage of the total vehicles produced by the manufacturer would need to be battery powered. The policy could also provide for the trading of "*EV Credits*" for instances where a manufacturer hasn't started manufacturing EVs.

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36 https://heavyindustries.gov.in/automotive

37 California Air Resources Board (CARB) ZEV Regulation (Cal. Code Regs., tit. 13, § 1962.2); https://ww2.arb.ca.gov/sites/default/files/2022-12/2021_zev_credit_annual_disclosure_ac.pdf

38 https://www.iea.org/reports/global-ev-outlook-2021/policies-to-promote-electric-vehicle-deployment

39 http://www.miit.gov.cn/n1146295/n1146557/n1146624/c5824932/content.html (in Chinese)

There is a multitude of material examining the impact of EV mandates[40]. It has been seen that mandates, on their own, have a positive effect on encouraging adoption of EVs. However, combining EV mandates with other policy interventions such as subsidies, taxes and restrictions on internal combustion engine vehicles has been found to be particularly effective[41].

On the other hand some may express misgivings about the reason mandates are needed for adoption of EVs and a question may arise as to why the market fails to incentivize EV adoption?

A market failure exists if net welfare is higher at an alternative equilibrium and if there is a hurdle that inhibits the market from reaching the alternative higher equilibrium.

It is seen that relatively new and smaller players are usually the leaders in introduction of EVs. Now, while such players may have the technological wherewithal to produce vehicles [in relatively smaller numbers to begin with] but they would typically lack the financial wherewithal to be able to provide infrastructure such as a roadside charging network or to be able to sell at volume to reap the benefits of scale. It is for these reasons that interventions such as subsidies, differential tax rates and mandates are considered.

We explore the impact of the interplay of measures such as EV mandates, taxes, subsidies etc. in a later section in this paper.

ii. *Increasing use of EVs within the Government*

Typically staff vehicles owned/operated by the Government [both Centre and State as well as semi-Government organizations such as institutions, autonomous bodies etc.] are within easy reach of a charger and often the gap between trips is long enough to recharge the batteries.

In addition, adoption of EVs by the Government is likely to have a salutary effect on the reliability and feasibility of the vehicles. This

[40] V.J. Karplus, S. Paltsev, M. Babiker, J.M. Reilly, Should a vehicle fuel economy standard be combined with an economy-wide greenhouse gas emissions constraint? Implications for energy and climate policy in the United States, Energy Econ. 36 (2013) 322–333. https://doi.org/10.1016/j.eneco.2012.09.001.

[41] The Economics of Electric Vehicles (Rapson, Muehlegger; 2022); https://www.nber.org/system/files/working_papers/w29093/w29093.pdf

would also create a demand for EVs. To begin with, this could perhaps be done on an incremental basis and may be made applicable only to staff cars and not to operational vehicles, which may need higher range and may not always have charging facilities readily available.

iii. *Addressing end of life issues etc.*

Since not many EVs have reached the end of their usable life, the used EV market, at least for LMVs, is at a nascent stage. Moreover, there are some concerns expressed about the cost of replacement of the batteries at the end of the recharge cycle [typically in about ~200,000 miles/10 years][42].

These issues could perhaps be addressed by incentivizing of leasing of EVs as opposed to outright purchases. The introduction of a preferential GST rate for leasing of EVs vis-à-vis outright purchase might be one way of incentivizing leasing.

In addition, there have been some concerns expressed regarding the safety of EVs, especially the risk of fires. In order to analyse this, the US National Highway Traffic Safety Administration commissioned a study of whether Lithium-ion batteries pose an exceptional fire risk[43].

The report concluded that the propensity and severity of fires and explosions from the accidental ignition of flammable electrolytic solvents used in Li-ion battery systems are anticipated to be somewhat comparable to or perhaps slightly less than those for gasoline or diesel vehicular fuels[44].

Further, the overall consequences for Li-ion batteries are expected to be less because of the much smaller amounts of flammable solvent released and burning in a catastrophic failure situation.

[42] https://www.evconnect.com/blog/how-long-does-an-electric-car-battery-last

[43] US NHTSA Report; Lithium-ion Battery Safety Issues for Electric and Plug-in Hybrid Vehicles

[44] https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/12848-lithiumionsafetyhybrids_101217-v3-tag.pdf; Page XVII

The Future is not what it used to be: Modelling for insights

Quantifying the impact of a set of policies, impacting multiple outcomes across a number of years is a particularly challenging task given that the variables are themselves changing across time and simultaneously impact and are themselves impacted by other variables.

For example, introducing subsidies, mandates, imposing taxes and changes in fuel efficiency would, over time, lead to faster adoption of cleaner technology and have a positive impact on reducing pollution levels.

However, in that time the macroeconomic indicators are also changing. For example growth in per capita GDP or demographic changes are likely to create demand for alternatives that hitherto may have been out of reach.

In order to understand such interactions, a macro-econometric model is often used as a forecasting tool. It is based on large economic datasets including national income, demographics, infrastructure growth, increasing urbanization etc.

Typically a large-scale macroeconometric model uses large amounts of data and is based on forecasts based on multiple correlations. These models are used to estimate relationships between different macroeconomic variables using regression analysis on time series data. At its core, a macroeconometric model is essentially a set of equations designed to explain the economy or some parts of the economy and their interlinkages.

In order to model for such complex scenarios, Cambridge Econometrics [a global economic consultancy firm] has developed a model called the *E3ME [Energy-Environment-Economy Macroeconometric]* model. *E3ME* is a macroeconometric model that integrates a range of social and environmental processes and provides for two-way linkages between the economy, wider society and the environment[45].

We use a submodule of the tool called the Future Technology Transformations:Transport (*FTT:Transport)* model - an evolutionary technology diffusion model for road transport technology[46] to model for the adoption of EVs.

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[45] Cambridge Econometrics; e3me - https://www.e3me.com/

[46] J.F. Mercure, A. Lam, S. Billington, H. Pollitt, Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2°C, Clim. Change. 151 (2018) 109–129. https://doi.org/10.1007/s10584-018- 2262-7

The FTT model simulates the evolution of fleets through technology diffusion dynamics that follow the standard theory on the diffusion of innovations[47].

The model makes use of coupled S-shaped curve (non-equilibrium) dynamics, driven by agent decisions, following preferences, decision rules and perceived incentives, calibrated to reproduce observed technology trajectories.

The FTT models use a version of discrete choice theory in which social influence is integrated. Its strong path-dependence and high policy resolution allow in-depth assessment of policy interactions. The modelling horizon used is the year 2050[48]. The model attempts to quantify the impacts of the following policy alternatives:

RT = imposition of a Registration Tax
FT = Fuel Tax
EVS = EV Subsidy
VT = Vehicle Tax
FE = Fuel Economy Standards
EVM = EV Mandate

In the Indian context, the following assumptions are used for the scenario analysis from 2020 to 2050.

Table 2: Policy Assumptions for Scenario Analysis from 2020 to 2050: India

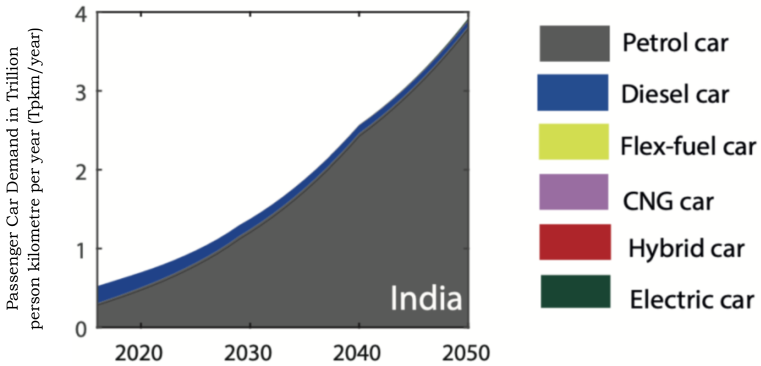
India	2020	2025	2030	2035	2040	2045	2050
Registration Tax	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]	Rs. 32,120 - 1,13,1500 [$440-$1500]
Fuel Tax	INR 54.75 $0.75	INR 54.75 $0.75	INR 54.75 $0.75	INR 54.75 $0.75	INR 54.75 $0.75	INR 54.75 $0.75	INR 54.75 $0.75
EV Subsidy	INR 73,000-2,19,000 [$1000-$3000]	INR 73,000-2,19,000 [$1000-$3000]	INR 73,000-2,19,000 [$1000-$3000]	INR 73,000-2,19,000 [$1000-$3000]	INR 73,000-2,19,000 [$1000-$3000]	-	-
Vehicle Tax	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]	INR 9490 - 32850 [$130-$450]
Fuel Economy Regulation	-	-	20%	20%	20%	20%	20%
EV Mandate	10%	10%	10%	10%	10%	10%	10%

[47] E.M. Rogers, Diffusion of innovations., Simon and Schuster, 2010

[48] Which policy mixes are best for decarbonising passenger cars? Simulating interactions among taxes, subsidies and regulations for the United Kingdom, the United States, Japan, China, and India. Aileen Lam, Jean-Francois Mercure

Using the above assumptions, various scenarios are modelled for. In order to obtain an initial [baseline] state, it is presumed that no policies are put in place. This leads to a scenario where petrol cars dominate the market by 2050 [Fig. 5][49].

Fig 5: Baseline Scenario Results: India, Passenger Car Demand in Trillion person kilometre per year (Tpkm/year)



Transport demand is typically driven by income, population, urban density, family structure and associated demographic factors. The demand estimation is done in two steps. First, on the basis of a constructed econometric model the demand for Passenger Light Duty Vehicles (PLDVs) is determined using fuel prices, income, urbanization, road infrastructure, urban density and fuel economy.

Subsequently, the econometric model is used to predict the future PLDV transport demand and a model is developed for projecting vehicle stock and likely future car ownership. The empirical model is described as under:

$$lnKM_{it} = \beta_0 + \beta_1 lnKM_{it-1} + \beta_2 lnY_{it} + \beta_3 lnFP_{it} + \beta_4 lnM_{it} + \beta_5 lnU_{it} + \beta_6 lnUD_{it} + \beta_7 lnFE_{it}$$

where;

$lnKM_{it}$ = *PLDV kms/year*
lnY_{it} = *GDP per Capital (USD)*
$lnFP_{it}$ = *USD/litre*
lnM_{it} = *Road Length (km)*
lnU_{it} = *Urbanization*
$lnUD_{it}$ = *Urban Density (population/km²)*
$lnFE_{it}$ = *Fuel Economy (litre/100km)*

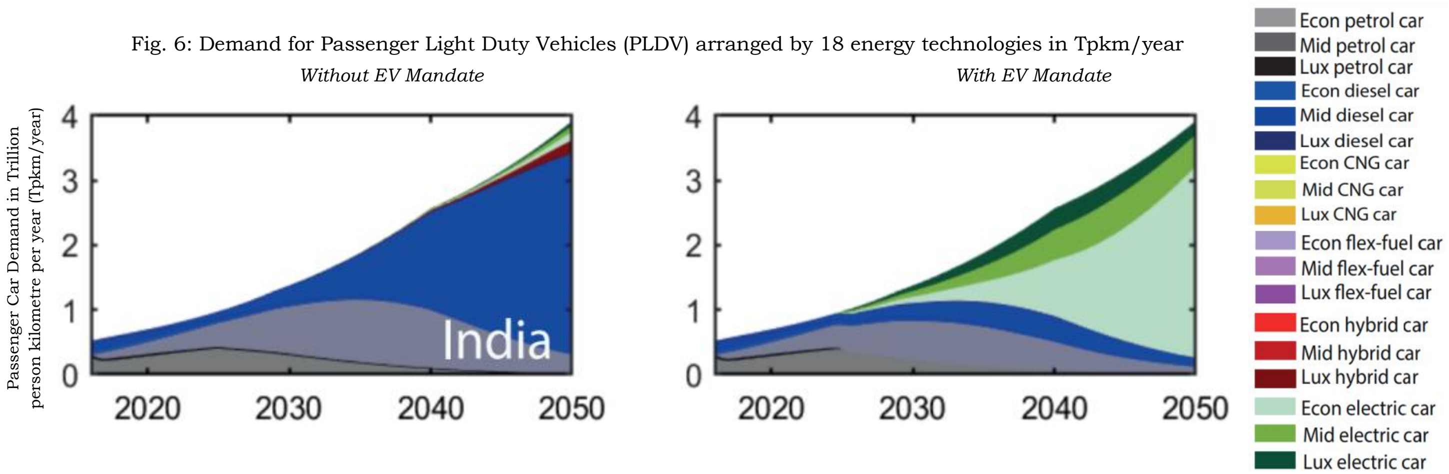
Demand for Passenger Light Duty Vehicles (PLDV) arranged by 18 energy technologies in Tpkm/year is shown in Figure 6. The figure on the left is the PLDV technological mix when vehicle tax, annual registration tax, fuel tax, EV subsidy,

[49] Which policy mixes are best for decarbonising passenger cars? Simulating interactions among taxes, subsidies and regulations for the United Kingdom, the United States, Japan, China, and India. Aileen Lam, Jean-Francois Mercure; https://doi.org/10.1016/j.erss.2021.101951

and fuel economy standards are combined. The figure on the right shows the PLDV mix when the EV mandate is added to the financial policies and fuel economy standards.

Fig. 6: Demand for Passenger Light Duty Vehicles (PLDV) arranged by 18 energy technologies in Tpkm/year

Without EV Mandate *With EV Mandate*



While the main thrust of our examination is the adoption of EVs, however for sake of completeness we also take a look at the environmental impact of our policy mix.

The E3ME model calculates global fuel use and combustion emissions. Combining projections for power demand, transport and heat and the E3ME models provide a relatively high definition dynamic coverage of global fossil fuel use and associated emissions[50].

Disposable income is calculated based on wages, GDP, price levels and employment. Fuel prices are derived from endogenous dynamic fossil fuel depletion and cost calculations (*Mercure and Salas, 2013*). Based on the above, the cumulative reduction of emissions from LMVs in India, under various policy alternatives is calculated. The results are as under [Table 3][51]:

Table 3: Cumulative emissions reduction ($MtCO_2$) from LMVs as a result of various policy interventions

Policy	**Cumulative emissions reductions for India (2016 to 2050) [MtCO2]**
Vehicle Tax	2.6
Registration Tax	169
Fuel Tax	13.6
EV Subsidy	5.1
Fuel Economy Standards	1350.3
EV Mandate	1247.2

50 Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2 °C (2018); J.-F. Mercure, A. Lam, S. Billington & H. Pollitt

51 Lam, A; Mercure, J-F (2021); https://ore.exeter.ac.uk/repository/bitstream/handle/10871/125146/ERSS_R2_clear.pdf?sequence=1

From the above, we see that the gains arising out of the mandating Fuel Economy Standards [for the period 2016 to 2050] are the highest, with an EV mandate coming a close second. Using the same model, the cost effectiveness of the individual policies is also calculated as under [Table 4].

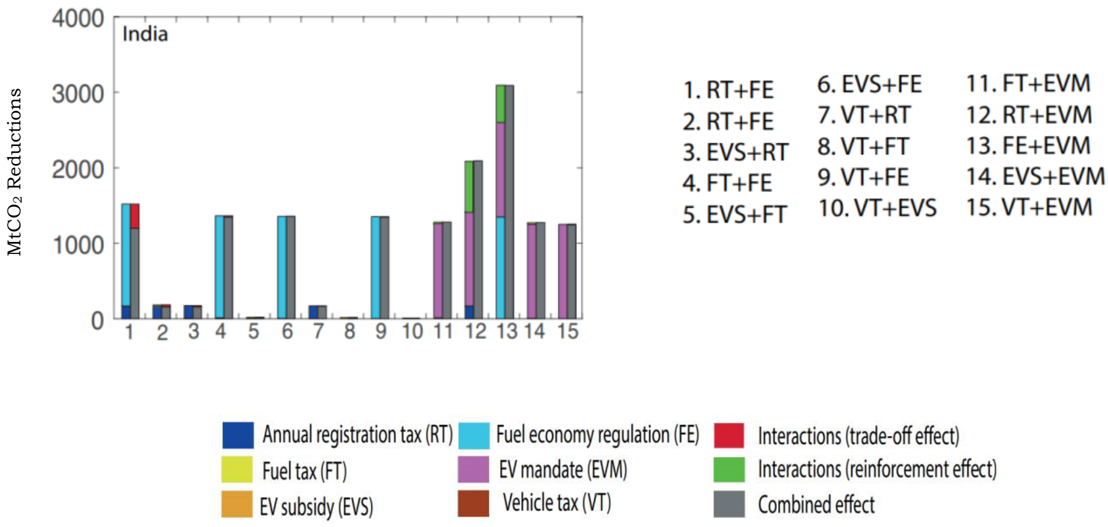
Table 4: Cost Effectiveness of individual policy alternatives (2016 US$ per tCO_2 avoided)

Policy	**Cost of Policy** **($/ton CO_2 avoided)**
Vehicle Tax	8038.3
Registration Tax	3459.9
Fuel Tax	2098.5
EV Subsidy	136.1
Fuel Economy Standards	10.6
EV Mandate	3.4

From the above, it is evident that EV Mandates are an effective tool for reducing CO_2 emissions.

However, in the above analysis, the various policy options are presumed to be implemented individually. Typically, this won't be so. Implementing multiple policies would lead to additive effects as well as to combined effects. To begin with, a model for combining two policy alternatives is used. The results are depicted as under [Figure 7].

Fig. 7: Policy effectiveness (in absolute values) and impact of interactions between two policies



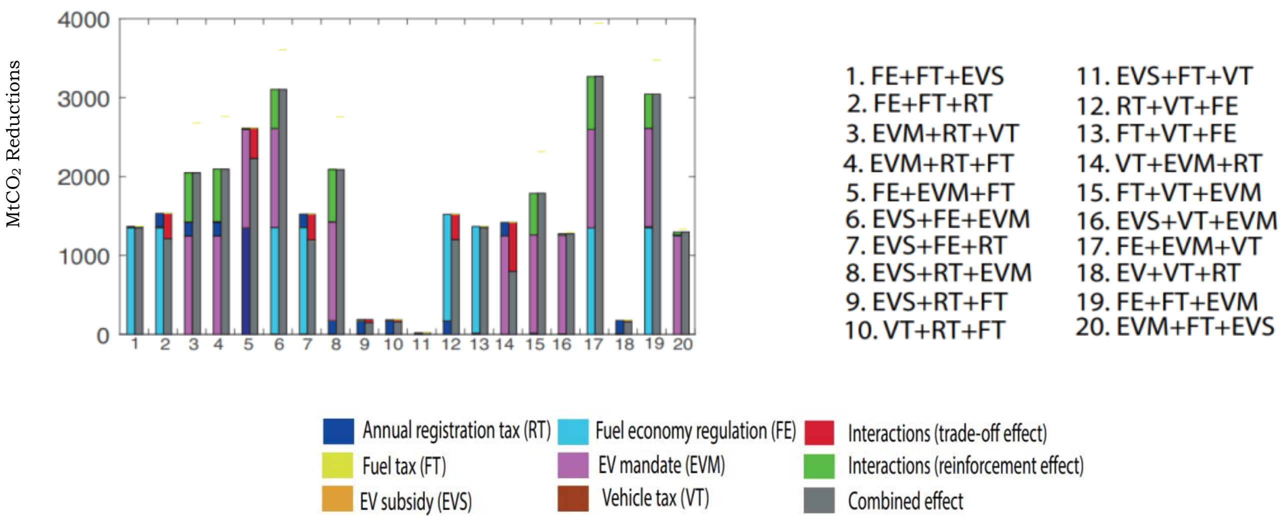
Policy effectiveness is defined as cumulative emissions reductions (between 2016 and 2050) achieved by a given policy or set of policies. The bars depict the effectiveness of policies in absolute terms (i.e. CO_2 emissions reductions achieved by the policies).

Whereas, the grey bars show the total effectiveness of two policies of the corresponding scenario. The green bar shows the reinforcement effect between the policies in the corresponding scenarios. The red bars show the trade-off effect between two policies in the corresponding scenarios (if any)[52].

From the above we see that combining Fuel Economy Regulations with EV Mandates leads to the greatest reduction in CO_2 emissions. Extending the same model to scenarios with three interacting policy interventions we get the following results [Figure 8].

Here too the greatest reduction in CO_2 emission comes from Fuel Economy Regulations + EV Mandate + Vehicle Tax [17].

Fig. 8: Policy effectiveness (in absolute values) and interactions between three policies.



Conclusion: Accelerating EV Adoption

As the economy grows, living standards, urbanization and labour market participation increases, vehicle ownership in India is only going to grow. This has been seen in most developing economies. Coupled with international commitments

52 Aileen Lam, Jean-Francois Mercure (2021); https://doi.org/10.1016/j.erss.2021.101951

to **reduce emissions**, we would need to look for cleaner alternatives to petroleum products.

This has relevance from an **energy security** perspective as well since, petroleum is the single largest constituent of our import basket. Moreover, worldwide there is a shift towards vehicles with cleaner fuels. EVs have been seen as being the most appropriate technology for long term reduction of emissions. This is likely to trigger demand for EVs. In addition to catering to our domestic demand, we need to be in a position to **service the global demand for EVs**.

Hitherto, our policies for promotion of EVs have focused on subsidies, tax breaks, charging infrastructure etc. While, we see a significant increase in the number of two- and three-wheeler EVs, the **adoption of EVs** in the **LMV** (cars) segment has **remained sluggish**.

We find that, high upfront cost/Total Cost of Ownership; range anxiety and logistical Reasons such as lack of model options, unknown resale value, early stage of EV technology development etc. act as barriers to the adoption of EVs. We examine each of the above points.

Using a tool developed by the International Energy Agency (IEA), we find that the total cost of ownership for EVs and ICE Vehicles breaks even at the 5^{th} year of ownership for small vehicles and by the 9^{th} year for mid-size vehicles.

Therefore, in terms of **total cost of ownership EVs compare well** with ICE vehicles and while the upfront costs for an EV might be higher, however given that multiple financing options are available the relatively higher upfront costs would be spread across the loan tenure.

Secondly, we find that for a typical use case the range being offered in EVs presently on the market should suffice. Typically, the calculation would hold even if we factor commercial use, in which case the fuel savings would be substantial to justify investment in an EV.

Given the rapid development in battery technology and reducing charging times coupled with an increase in the EV charging infrastructure in the country, the **anxiety regarding range seems** rather **unfounded**.

However, in the immediate term the need would be to rapidly scale up our publically accessible EV Charging network. Given their reach, numbers and ready availability of space we recommend using existing petrol pumps for this.

Further we recommend the following **policy interventions** for enhancing the adoption of EVs:

- Introduction of transferable mandates prescribing for a certain percentage of vehicles manufactured to be EVs. This has been seen as an efficient way of encouraging adoption of EVs. We use the E3ME macroeconometric tool to model for the likely increase in adoption.

- To deal with end of life issues for EVs, we suggest encouraging leasing of vehicles [as opposed to outright purchase]. This can be done by introducing a suitable GST rate differential for leasing.

- Greater diffusion of EVs in the Government's fleet is one way of seeding demand. Such a move would have a demonstration effect on the public and provide manufacturers feedback on the user experience.

We also examine the impact of the greater adoption of EVs on reduction of emissions and what is the likely impact of various policies used individually and in conjunction with others. Here too we find that an EV Mandate causes the greater reduction in CO_2 emissions at the lowest cost.

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The views expressed are the author's own and are expressed purely in his personal capacity.

Key Words: Transportation Economics, Environmental Taxes & Subsidies, Energy, Externalities
JEL Classification Codes: H23; Q49; Q55; R4

Igniting the Bright Spark

Examining the impact on Electricity Generation

Prooemium

This is an addendum to the paper titled "Igniting the Bright Spark: Through the Looking Glass on Electric Mobility in India". Here we explore the impact on the demand for electricity that promotion of Electric Vehicles (EVs) is likely to result in.

This is particularly pertinent given the fact that a majority of electricity production in India comes from thermal power which is often seen as having an adverse environmental impact.

Electrifying the Future

We approach the question of a likely surge in demand for electricity on account of increased adoption of Electric Vehicles (EVs) from three perspectives.

Firstly, electric engines are far more efficient from Internal Combustion Engines (ICEs)[53]. This has already been alluded to in the paper [Page 5]. The *tank-to-wheel* (TtW) efficiency [i.e. efficiency of the engine vis-à-vis the fuel supplied] for an electric vehicle is estimated to be as high as 73%[54].

This figure is likely to rise up to 90% when we take into account newer technologies such as *regenerative braking* - a technology to that makes use of the vehicle's momentum to recover energy which would otherwise have been lost to the brake discs as heat; the kinetic energy is converted into a form that can be either used immediately or stored until needed.

In comparison, for an ICE vehicle the (TtW) efficiency is estimated as being between 17% to 40%[55]. A more detailed exposition on the TtW efficiencies has been

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[53] Comparison of the Overall Energy Efficiency for ICE Vehicles and EVs [ALBATAYNEH1, N. ASSAF, ALTERMAN, JARADAT; 2020]

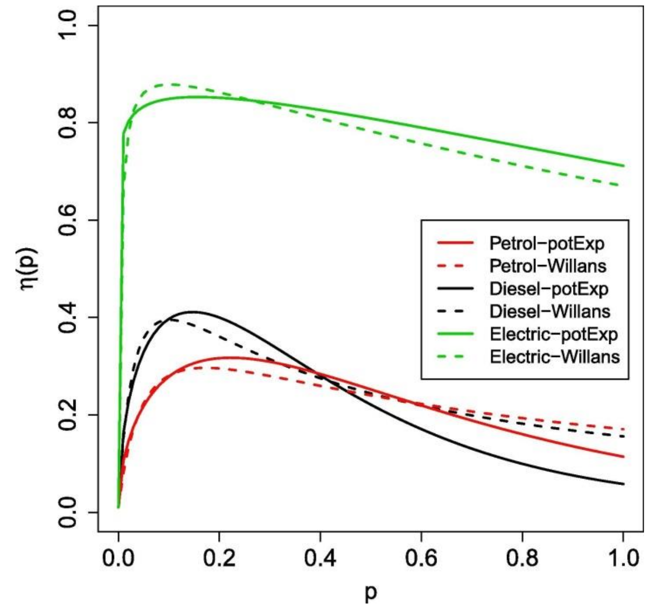
[54] Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions (H. Helms, M. Pehnt, U. Lambrecht and A. Liebich; 2010)

[5555] https://enveurope.springeropen.com/articles/10.1186/s12302-020-00307 8#:~:text=Electric%20motors%20have%20a%20higher,whereas%20conventional%20vehicles%20do%20not.

done by (*Hjelkrema, Arnesenb, et al*; *2020*) [56] who have estimated the energy efficiencies using two theoretical models [*potExp* & *Williams*].

In interest of brevity, we confine our discussion to the results of the study which are succinctly captured in Figure 1.

Fig. 1: Energy Efficiencies of Electric and Petroleum Engines



x-axis *(p)* is the Utilized Engine Power while the y-axis *η(p)* is the resulting energy efficiency coefficients for each fuel type

We may see that the overall efficiency of electricity is much higher than for fossil fuels, peaking higher at far lower engine power. Also, the peak for diesel vehicles occurs at about 40% efficiency, while for petrol vehicles the peak is found to be just above 30% efficiency[57].

While the endogenous efficiency of an electric engine is apparent, a better estimate could perhaps be to use *Well-to-Wheel* (WtW) efficiencies [i.e. efficiency across the entire energy supply chain].

Total WtW efficiency of gasoline vehicles is estimated to be between 11% to 27%. The WtW efficiencies are comparable for EVs powered by electricity from a fossil fuel powered power plant. However, if renewable energy is used the overall efficiency for electric cars is estimated to be in the range of 40% to 70%[58].

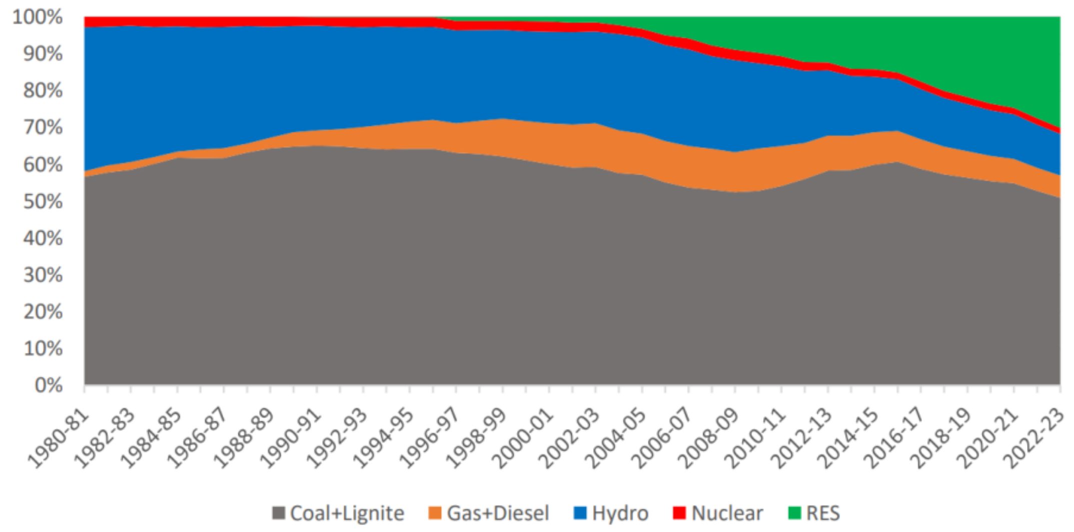
[56] Applied Energy; https://www.sciencedirect.com/science/article/pii/S0306261920309752#f0005

[57] E.P. Kasseris, J.B. Heywood; *Comparative analysis of automotive powertrain choices for the next 25 years*; SAE Trans (2007), pp. 626-647

[58] Comparison of the Overall Energy Efficiency for ICE Vehicles and EVs [ALBATAYNEH1, N. ASSAF, ALTERMAN, JARADAT; 2020]

This ties-in with our second perspective – the likely energy mix in India in the near to medium future. As per a report of the Central Electricity Authority (CEA), Ministry of Power, the installed capacity for Renewable Energy Sources (RES) has increased consistently in recent times [Figure 2][59].

Fig. 2: India's Installed Capacity Mix for Power Generation



Further, a projection of the installed capacity in 2029-2030 [as compared to that in 2021-2022][60] shows that the share of renewable especially Solar and Wind in the installed capacity is likely to increase substantially whereas the share of Coal and Lignite falls sharply [Figure 3, 4].

Fig. 3: India's Installed Capacity Mix [2022 v. 2030]

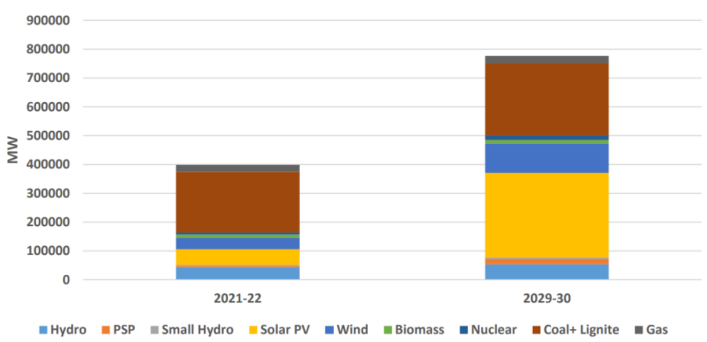
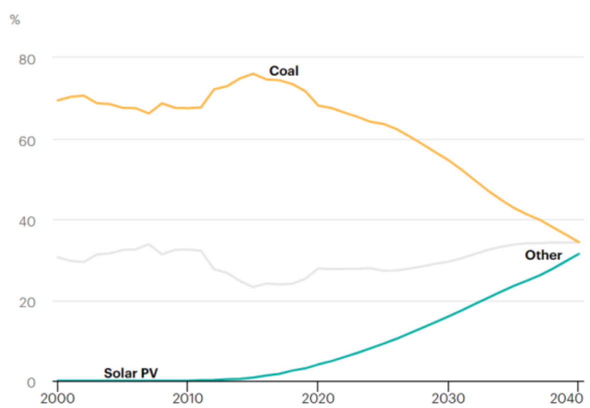


Fig. 4: Change in Share of Power Generation



59 https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

60 Report on Optimal Generation Mix 2020 Ver 2.0, Central Electricity Authority, Ministry of Power

Thirdly, use of electric vehicles helps disperse the sources of generation of the energy, thereby dispersing the pollution over a larger area. Moreover, the expansion of electric mobility significantly reduces the dependence on imported petroleum oils.

It is for these reasons that both from the energy demand as well as the pollution perspective electric vehicles make a lot of sense.

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