Importance of Battery Recycling and Swapping: The Next Inevitable Step in Electric Vehicle Supply Chain

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Abstract - The purpose of this study is to fathom the importance of battery supply chain including battery swapping and recycling as well as the charging infrastructure as nodes in the electric vehicle (EV) supply chain in India. It also delves into the ways in which Faster Adoption and Manufacturing of Hybrid and Electric Vehicles or FAME II is addressing these issues. One of the key obstacles in the way to the speedy adoption of EVs is range anxiety. A healthy and expanding network of charging infrastructure has a very important role to play in penetration and propagation of E-mobility. Fame II is also committed towards creating charging infrastructure besides providing demand incentive. The problem of battery waste generation which is an obvious fall out of e-mobility adoption is intended to be addressed through battery recycling and battery swapping – both are at a nascent stage in India with significant potential for growth. The study looks into both primary data (gathered through survey) and secondary data (collected from authentic data sources both public and private) sources. The mix of empirical research and direct face-to-face interview with consumers helps to better substantiate our argument. Adoption of E-mobility is unavoidable so is battery waste generation. Battery recycling and battery swapping can be the two technologies that assume enormous importance with the expansion of EV market in India. Range anxiety, another key concern of the potential and present EV owners, can be taken care of by ramping up charging infrastructure – a key area of focus of the Indian Government in its FAME I & II schemes.

Key Words: *electric vehicles, vehicle batteries, lithium-ion batteries, supply chain, value chain.*

1. Introduction

Electric Vehicles (EVs) have started going mainstream since they are cleaner, more powerful, less noisy, and more convenient. Tesla is leading the way with Model-S [1]. At present, governments across the world are placing a lot of emphasis on the adoption of e-mobility and hence on the development of the EV industry, lending strong support through both policy and funding, and actively encouraging the promotion spread of electric vehicles [2]. Developments in the e-mobility industry and growing investigative and exploratory efforts linked to vehicles using alternative fuels, besides increasing environmental concerns are suggestive of the fact that a changeover from the internal combustion engine (ICE) technology to EV is not only essential but is also inevitable [3]. Furthermore, the use of UAVs in retail deliveries by Amazon and Walmart is focused towards solving the problem of last mile delivery as well as the speed of delivery under an hour. However, UAVs as a transportation mode have limited flying range due to limited battery life and the range anxiety can be mitigated by using battery swapping stations in the planning horizon [4].

Beyond a doubt EVs do not pollute the air as much as ICE vehicles running on fossil fuels do since they are zero emission but in general, the resources utilized in battery manufacturing are harmful to the environment [5]. Mining and treating of metals including manganese, copper, lithium, and nickel requires lot of energy and is capable of releasing toxic compounds. Electrolyte and salt ($LiPF_6$) that are used as separator in any common li-ion battery are primarily organic compounds which pose health hazards to humans on exposure [6], [7]. EVs also generate toxic battery waste having adverse environmental implications [8], [9]. These have emerged as important obstacles to implementation of e-mobility besides range anxiety

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and inadequacy of charging infrastructure in most countries of the world including India.

Buyers show keen interest in buying from companies that try to work out a solution for these issues. It is important for Organizations to adopt a strategic approach to the supply chain management of batteries that is based on the long-term relationship with suppliers and customers [10]. Many EV manufacturers are looking at recycling the batteries, using battery swapping technology, providing charging solutions etc. These form important nodes in the EV supply chain. This study is aimed at understanding the importance of battery supply chain including battery swapping and recycling as well as the charging infrastructure as nodes in the electric vehicle (EV) supply chain in India. It also delves into the ways in which Faster Adoption and Manufacturing of Hybrid and Electric Vehicles or FAME 2 is addressing these issues and what services the customers expect to be provided in order to mitigate the range anxiety.

2. Literature Review

EVs do promise of a cleaner and greener environment, cheaper maintenance compared to their ICE brothers and lower fuel expenses. The question arises as to – a) why is there so much delay in implementation of e-mobility across the world? b) Why are developing countries like India lagging seriously behind in implementation compared to their developed counterparts despite Government support and why do implementation targets get relegated?

When we try to analyze the problem, it appears that there are 2 key issues involved. One is the range anxiety among customers and the other is environmental concerns.

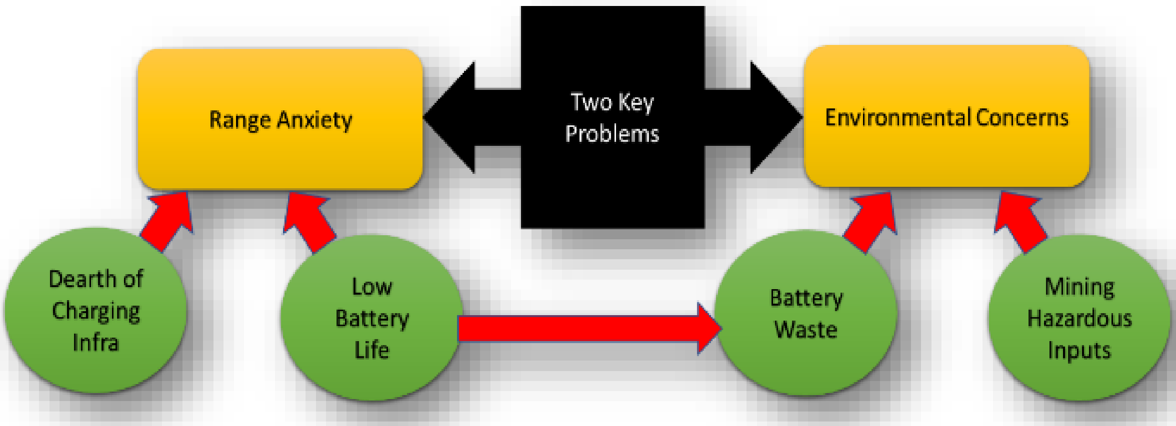

Figure 1: Breaking Down the Problems with EVs

2.1. Environmental Concerns

There are certain serious environmental issues associated with batteries used in EVs and the raw materials going into manufacturing of the EV battery packs.

2.1.1. Low EV Battery Life

In general, EV batteries will have to be replaced every 7-10 years in case of vehicles that are smaller in size and every 3-4 years if the vehicles are as big as buses and vans [11]–[13]. A preponderance of EV batteries have 160,000km (100,000 mile) drive limit or 8-year warranty [11]. Tesla Roadster uses a lithium-ion battery pack that is expected to have a 5-year lifespan or last 100,000 miles. On completing this span, the pack must be replaced [14], [15].

2.1.2. Environmental Concerns

As a whole these battery stockpiles are likely to surpass 3.4 million by 2025, which is a significant upsurge (62-fold increase) from 55,000 recorded in 2018 [16]. Considering the 2017 EV sales volume, UK researchers foresee the generation of massive 250,000MT (approximately 0.5 million cubic meters) of "unprocessed battery pack waste" on completion of life-cycles of these EVs in another 15-20 years roughly[17]. There are battery manufacturing technologies that use toxic materials and on their disposal will pollute the environment through release of these hazardous substances [18].

Cobalt, an indispensable input for rechargeable batteries used in both smart phones and EVs [19], does not come from mines controlled and operated by global mining firms that follow guidelines and regulations but from frivolous artisanal mines that earned a lot criticism for being associated with child labor and human rights exploitations by Amnesty International, among others [20], [21]. Besides bearing the risk of toxic gas expulsion if damaged, EV batteries have another significant disadvantage. The extraction of the key ingredients, lithium and cobalt, have the potential to cause serious water pollution and depletion in water levels and other environmental concerns [18]. The available literatures, therefore, correctly emphasize on the virtues of recycling.

2.1.3. Need for Battery Recycling

The ongoing EV boom will generate 11MT of consumed lithium-ion batteries that will have to be recycled during 2017-2030 [18] to avoid accumulation of environmentally hazardous battery waste. Typically, after completing a few thousand charging cycles a normal EV lithium-ion battery's performance will starts to go downhill rapidly [22]. The battery loses its capability to run the vehicle as it should be. Replacement by a new one becomes a necessity. However, this in no way means that the battery has reached the end of its life. before being discarded completely as useless waste materials, these spent batteries can still live for 2-3 lives provided they are put to less intensive uses. for this, however, the right kind of markets and techniques need to be primed and made ready to breathe a little more life into these seemingly used and exhausted batteries. Modern day examples of such businesses practice are the telecom-tower operators and utility companies, who are trying to extract the best out of these recycled batteries in order to build up on their operational cost front [22].

Batteries used in EVs are not cheap since they are brimming with raw materials that are sparse in supply. These batteries pose threat to the environment as well since their disposal is a complicated task, and as of now disposal economics continue to remain unattractive [22]. Normally, an **EV** battery would contain a number of important and reusable substances such as nickel, cobalt, and copper. Recycling these batteries will help to reuse these materials, diminish pollution and may even present the opportunity to benefit from it. Organizations that recycle EV batteries even sell EV them to individuals who for their personal use [23]–[25]. Management of battery life cycle provides a good opportunity to overturn what seems to be a constraint to the evolution of a new attribute that has the potential to step up and expand EV sales in the times ahead [22].

2.2. Range Anxiety

For battery electric vehicles (BEVs), both commercial and personal use vehicles, energy has to be replenished at frequent intervals due to the daily tasks they perform and their restricted driving ranges, giving rise to what is called "range anxiety" that has been discussed in sec 2.2.2.. Accordingly, the key impediment for the electric transport system, both public and private, that needs to be overturned, is the replacement of energy. Currently, the energy replenishment technologies are categorized under 2 key heads – charging the battery in the vehicle itself and swapping the EV battery [26].

2.2.1. EV Battery Range

EV batteries play the key role in determining not only range but also cost of the vehicle [27]. Several EV models have been introduced in the car markets Nevertheless, large-scale uptake of e-mobility is still hard to foresee in the near future since there is a serious shortfall of services available for divers of these cars. US Department of Energy's study suggest that most people would not go for an EV purchase due to range anxiety of the drivers [28]. When it comes to electric vehicles, range is *the* all-important stat. Whether or not you make it to the next public-charging spot, are able to complete your daily commute, or are instead stranded on the side of the road depends on it [29]. The following figure (Figure 2) lists the 10 models that accounted for 94% of EV sales in US in 2017 and gives their ranges.

Manufacturer	Model	Range (miles)
Tesla	Model S	259–335
Tesla	Model X	295
Tesla	Model 3	220–310
Chevrolet	Bolt EV	238
Nissan	Leaf	151
Fiat	500e	84
VW	e-Golf	126
Ford	Focus Electric	118
BMW	i3	114
Kia	Soul EV	111

Figure 2*:* EV Ranges [27]

2.2.2. Range Anxiety

Mobility based on EVs or what is called e-mobility is believed to be a key agent in cutting down pollution and carbon emissions, in present day smart cities. Nevertheless, irrespective of worldwide interest in adopting e-mobility that is bringing in investments to the auto industry from across the globe, the user acceptance level continues to remain quite subdued, mainly on account of the deficiency in support services such as charging. This tops the list of the key concerns for what is being referred to as the "EV driver's anxiety", and is responsible for people to think about mobility using EVs to be suitable for short distances only [28]. Today, the principal concern amongst the prospective mass buyers is range anxiety.

Range anxiety refers to the overblown apprehension or concern of something that might happen in the future while using an EV, that is yet to, and is likely not to, transpire. That precise something here refers to being stranded at some place with a battery that is dead rendering the car useless [30]. This anxiety is heightened by the absence of adequate charging infrastructure – charging stations at regular intervals. Despite EVs attracting larger interest from customers and auto manufacturers, there has been very little improvement in the disadvantages resulting from limited range and the present shortage of public recharge station [31].

Conventional EVs are disparaged for having less range than a traditional ICE vehicle. Range anxiety looks more like an illusion than an actual concern that has been ingeniously disseminated by the mainstream media. In general, there will be a flattering piece of literary work that will talk about the innovation and ingenuity associated with an EV and then will put up the concern about the low range of EVs and the 'anxiety' it causes. More often than not these literatures pinpoint the uselessness of EVs for commuting long distances due to the impracticality of and considerable time consumption on account of recharging. As a result, the reader either overtly, or covertly through inference, gathers the idea that EVs are yet to be ready for any kind of application [32].

2.2.3. Need for Battery Swapping and More Charging Stations

Range comes under such strong inspection due to the fact that on an average EVs are able to travel just about 50% of the distance travelled by gas-powered vehicles until a "fill-up" becomes necessary and also because gas stations are far more plentiful compared to EV charging stations or fast chargers [33]. This creates the necessity for ramping up charging infrastructure. That does not simply mean erecting charging stations along highways. Within the city as well charging facilities should be available at regular intervals across the city and additionally at parking lots in workplaces, housing complexes, shopping malls, public parking lots, bus depots, etc. So far, because of policy, procedural and monetary constraints, the deployment of charging stations, charging piles and other charging infrastructure has not exactly been very extensive [34].

Charging the batteries of large commercial vehicles such as a bus usually takes several hours even using quick charger. This makes it inefficient for operation besides being damaging for the battery lives [35]. So, having charging stations do not effectively solve the range anxiety problem. The industry has come up with a novel proposal to offer a solution to the problem of range anxiety that revolves round using "swapping stations," at which washed-out batteries can be replaced by recharged batteries even in the middle of long trips [36]. Here therefore, the requirement is to establish swapping stations at regular intervals rather than charging station. EV Supply Chain

2.2.4. EV Battery featuring in EV Supply Chain

Waste batteries pose serious challenges for producers of EV batteries in connection with end-of-life waste-management. Producers, therefore, should try to gain access to strategic elements that are regard as crucial for manufacturing EVs. Recycled lithium-ion batteries from EVs are supposed to provide an important secondary source for these crucial inputs [37].

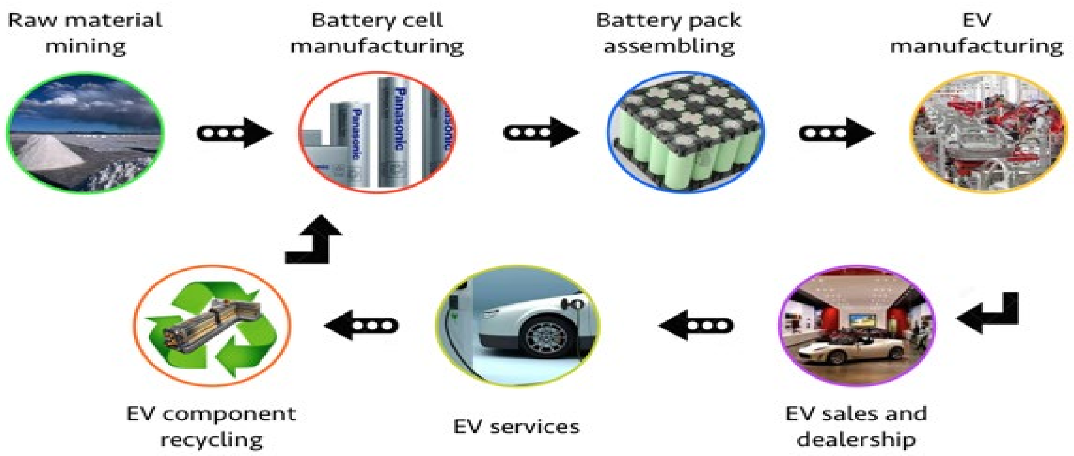

Figure 3: EV Supply Chain [38]

Less demanding, secondary usages for these recycled EV batteries are expected to prolong their durations of service, or in certain cases refurbishment might also be contemplated. At the end of the day, however, the battery needs to be processed in a manner that permits recycling all the valuable and/or hazardous components and materials [39].

2.2.5. Battery Recycling

Recycling offers the opportunity for the reduction of battery life cycle costs through recovery and repossession of pricey substances. In so doing it helps to anticipate the expenses that need to be incurred for the disposal of hazardous waste materials. This is why one of the key objectives of the EV power source developers is recycling of maximum possible material at the end of their useful lives as [39].

It is obvious that exponential increase in the number of EVs is one of the key reasons behind the fundamental and comparable development of the market for rechargeable batteries. However, the Special issue on strategic battery raw materials, a report released by the United Nations Conference on Trade and Development [21]has highlighted quite a few socio-economic and environmental effects of mining the raw materials that are essential for battery manufacturing. These issues need to be handled in a timely manner, failing which these issues are likely to peter out the importance that EVs are receiving as a form of transportation that has better conscientious [40].

2.2.6. Battery Swapping

At a battery swap station (BSS), a BEV will be able to exchange its exhausted battery pack with one that is fully charges with a negligible delay in time. The depleted battery packs can then be recharged at the station and used later for swapping with the batteries with other arriving battery-operated electric vehicles [36]. This mode of battery swapping looks as if presently it is better suited for implementation of e-mobility in case of public transport system [35] . Compared to plug-in charging solutions, battery swapping has certain advantages such as lesser replacement cost and significantly shorter duration of service [41].

2.3. E-mobility in India

Electric mobility presents a viable option to address the challenges associated with the climate change commitments made by Government of India (GoI) which only makes it pertinent to introduce alternative means in the transport sector that can be combined with India's ongoing economic growth, growing urbanization, increasing travel demand and India's energy security [42].

The electric vehicle market in India has gained a lot of momentum following the implementation of Faster Adoption of Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) scheme. The total EV sales in 2018 was recorded at 365,920 Units was expected to increase at a compounded annual growth rate (CAGR) of 36% till 2026. According to industry body Society of Manufacturers of Electric Vehicles (SMEV) Electric vehicles sales, excluding e-rickshaws, grew by 20% in India in 2019-20 [43] .

The Indian EV battery market was estimated to be worth US$ 520 Million in 2018 with a forecasted growth rate (CAGR) of 30% till 2026. In 2018 the total MWh addition touched 4.75 GWh and is expected to grow till 28.0 GWh by 2026 [44]. Availability of adequate charging infrastructure is believed to be one of the major requirements for speeding up the adoption of electric vehicles in India [42].

2.3.1. Environmental Concerns & Battery Recycling Opportunity in India

Once a battery reaches the end of its lifespan, what is left behind is what is called battery waste. It comprises of massive quantities of chemicals including cobalt, electrolytes, lithium, manganese oxide and nickel. Most of these battery wastes is dumped in landfills. [45]. India does not have the requisite legislations in place to prevent unlawful dumping of waste lithium batteries. None of these consist of any consistent or organized set of rules that can be implemented for the safe disposal of EV batteries [45]. Unfortunately, Li-ion batteries, have been mentioned, neither in any of the frameworks designated for end-of-life treatment of batteries nor in any recycling framework.

Presently India is not only unsuspecting but distressingly ill-equipped for the downright volume waste expected to be generated from EV batteries in the near future [45]. India has the potential to turn into a lithium waste dumpsite not only for domestic EVs battery waste, but also for the import of exhausted batteries. These spent batteries comprise of materials that, unless properly recycled or treated, can cause serious damages to both the humans and the environment [46]. On top of this, lithium reacts spontaneously with moisture to form hydrogen gas that can cause major hazards such as fire and landfill explosions [46], [47].

An industry research expects Lithium-ion battery market in India is to reach 132 GWh by 2030 from 2.9 GWh hit in 2018 registering a CAGR of approximately 35.5% [48]. The yearly recycling market in India is projected to reach approximately 22-23 GWh by the year 2030 - a $1,000 million prospect [49].

Tata Chemicals Ltd, one of the pioneers in electric cars, started a plant for recycling li-ion battery, in Maharashtra in 2019. Mahindra Electric too had articulated its proposals to support EV battery recycling, taking help from a supply partner, following a met hod that is comparable to the methods used in recycling batteries used in cellular phones [49]. Industry participants are of the opinion that several challenges and possibilities exist in closed-loop recycling of lithium ion batteries. The technology for recycling of these batteries is still at an incipient stage. The variations in design creates a lot of difficulty in adopting a standardized process for battery recycling thus reducing the process efficiency [50]. The process of recycling is able to help reclaim nearly 50% of the expensive metals, that include aluminium, cobalt, copper, lithium, ma nganese and nickel. Once reclaimed these metals can then be put to secondary use [45]. Besides low recycling efficiency, the excessive cost of recycling acts as a big deterrent [50]. According to the industry sources, the cost associated with recycling of lithium-ion battery in India is estimated at Rs 90-100/ kg, approximately. Astronomical sums need to be invested in technology to collect, transport and manage the resources used in a Lithium-ion battery facility. The profile margins, however, are quite low. At least 5 years are needed to break even – before any cost recovery and profit booking can take place [49]. There is no doubt that the job involving collection and transportation of waste lithium ion batteries is quite a difficult task. Presently, no more than 5% of the exhausted lithium-ion batteries, are being collected [50]. In the absence of any scientific guiding principles and regulations defined clearly and distinctly for li-ion batteries, the return on investments made in setting up recycling units remains poor for this capital-intensive initiative [45]. It is expected that, as the lithium-ion battery market grows and its compositions become standardized, these challenges would dwindle away in due course. Despite proposal by the Union government for framing of a much-awaited recycling policy In October 2019, it is still awaited [45].

2.3.2. Range Anxiety & Inadequate Infrastructure

In India, an electric car can travel up to a maximum distance of approximately 200 km on a single charge. This is steadily improving with newer models. Though it is true that driving range is a major concern among the present and potential EV owners, most vehicle owners rarely make trips that are long enough to exhaust the supply of electricity midway. The driving range offered by current EV models in India are good enough to fulfill the needs of usual, inter-city travel. The EVs that are presently obtainable in the Indian market are easily able to complete short and medium distance trips [51]. Nevertheless, the need for sufficient and suitable charging infrastructure is very real and very much present.

According to industry players, the travelling range 200 km – 250 km for every single (battery) charge appears to be the optimal EV running range. Anything above this range will not help in achieving optimization in terms of price (of the EV) and range (it can travel). The industry participants believe a 220 km running range will be able to overcome the range anxiety and with the precise kind of charging infrastructure, this vehicle range should totally work for the country's EV market [52], [53].

2.3.3. *Role of FAME*

India has set in motion the directive for adoption of EVs, akin to its western brothers and China, using schemes, for instance, Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) I and FAME II [54]–[56]. Fame I that was adopted in 2015 provided subsidies for electric 2- and 3-wheelers, hybrid and e-cars and buses. The Fame-II scheme was launched on April 1, 2019 following the success of its previous version that set the platform for preliminary roll out of e- mobility products in the country [55].

Despite the fact that FAME I provided the much-needed backing for the development of charging infrastructure within the country, the adoption of E-mobility continues to face the hurdles caused by the lack of obtainability of adequate charging infrastructure. Moving on, in the phase II of the FAME scheme, the government, both at the central and state levels, has augmented its support for the growth and expansion of charging infrastructure throughout India, which is expected to make the adoption of EVs in India easier [57].

FAME II intends to create demand for EVs through provision of incentives. One of the key obstacles in the way to the speedy adoption of EVs is range anxiety. A healthy and expanding network of charging infrastructure has a very important role to play in penetration and propagation of E-mobility. FAME II also intends to create charging infrastructure through creation of 2700 charging station in metros between 2019-2022 and establishing charging stations in major highways [55].

To avail the subsidy, e-scooters need to have a range of at least 80 km, should be locally manufactured and should not use lead-acid based batteries. The stringent eligibility criteria for claiming subsidy under the FAME-II scheme has acted as a deterrent to 2-wheeler EV sales growth which is one of the main reasons why 2-wheeler electric vehicle sales have come down in fiscal year 2020 [54].

2.3.4. *New Government Initiatives*

The GoI has adopted new set of guidelines to further nudge the adoption of EVs. The new proposals recommend the setting up of a network of charging Infrastructure for electric vehicles, pan India, but in a phased manner. These new set of rules are expected to make the strive to ensure that at least one charging station is installed in a 3 km X 3 km grid in towns and cities (megacities with a population of 4 million-plus in the first phase and big cities such as state capitals in the second phase) and one charging station is erected at an interval of not less than 25 km on both sides along highways [58]–[60]

3. Research Methodology

Our research methodology is a mix of primary (survey) and secondary research (data drawn from public domain). Beyond a doubt there is significant scarcity of studies that talk about the impediments in the adoption of technology that have appeared as a result of institutional abysses that exist in the emerging economies such India, we have resorted to an exploratory approach.

3.1. Survey

In order to substantiate our stance of the adoption of e-mobility and its connection with battery recycling and battery swapping, we have employed a research methodology that is a mix of gathering and analysis of both primary and secondary data. For the primary data we have employed survey as a methodology using in-depth interviews. Being an assortment of data gathered from a sample of individuals through their responses to questions [61], surveys can be effectively employed to evaluate requirements, estimate demand, scrutinize impact of particular incidents and substantiate an argument [62]. The objective of our survey was to reflect the attitude of people towards adoption of e-mobility, customers' readiness and willingness for it, the hindrances being faced by customers, and a set of other purposes. Survey method has been used for both quantitative and qualitative study. The survey incorporates the views of consumers in order to ensure that we represent the demand side of the equation as accurately as is possible and our inferences are not biased.

The sample survey was initially posted to 2000 people in Nov 2020 and was terminated when the requisite sample size was obtained. The final result comprises 350 participants, all of whom stated Indian residency and a minimum age of 18 years, had completed the survey. The survey involved answering 33 questions divided into 5 sections, all of which were multiple-choice style. The survey was run over a period of 3 days to average the regional and demographic biases. The sampling frame consisted of the auto consumers in India and a simple stratified random sampling method was taken utilizing a random number generator tool. The survey was conducted on an online platform and the response rate was 17%.

The sample consisted of Identified Target Audience, both male and female, all of whom are automobile consumer and 18+ years in age, residing in India. The pre-launch testing ensured that the survey could be undertaken by anyone using any device including mobile, desktop and tablet. the survey was mailed using the electronic mail [62] sending a link to the target audience inviting them to participate. All respondents receive a unique survey URL that can be used only once. This ensures avoidance of data duplication. Since the respondents belong to a specially selected group of people for taking part in automobile related sample surveys, the incidence rate is assumed to by 100%.

Our analysis scrutinized consumer perceptions along with their attitudes toward EVs and e-mobility policy, with the purpose of better comprehending the perceived hurdles in the way of EV ownership and identification of the necessary public policies that would be most conducive to consumers in choosing an EV for their next vehicle purchase [63]. The questions were so designed as to elicit responses that can highlight how important is it for the government to ramp up EV charging infrastructure and provide pep up demand to ensure faster adoption of e-mobility in India, how consumers' purchases are influenced by range anxiety and what policy improvement are required.

By conducting the survey, we intend to quantify the results for the concept of how the change in the mobility ecosystem from ICE to EV (product innovation) in a developing market like India is impacted by the state of affairs prevailing in India – such as government policy, existence of adequate charging facilities, ranges offered by existing electric vehicle models. The questionnaire started with a generic section to make the sample audience warm-up to the questionnaire wherein it concentrated on setting the boundaries by geofencing the target sample in terms of age, region, driving preferences, income bracket etc. In the subsequent section of the survey, a general perception of the market towards the innovation in the product was quantified in terms of the responses obtained. This gave us a quantified insight into the market perception (positive or negative) when the product innovation impacts the e-mobility adoption. The sample survey was then steered towards quantifying the variables of specific challenges in the implementation of the features of EV innovation such as 'Full self-drive' software or the charging infrastructure or the price of the product itself. The final sections of the survey focused on the verticals of the change in the ecosystem of both Government as well as the Society and quantification of the variables of policy initiatives, emission standards, and infrastructure facilitation.

3.2. Secondary Data

Secondary data refers to the data that has already been assembled through primary sources and has been made readily available for scholars and researchers so that it can be used for their own research [64], [65]. The secondary data is collected from renowned websites belonging to government, research agencies, news agencies, journals, newspapers and other reliable sources to ensure the authenticity of the data. The data so gathered requires less or no cleansing. Existing data is ready for use as it is summarized and collated to augment the overall effectiveness of **research** [64].

Secondary data analysis, therefore, involves analysis of facts and figures that had been gathered by someone else for a different primary purpose. The use and application of this existing data offers a feasible option for researchers who might have constraints in terms of time and resources. Secondary analysis refers to an empirical piece of work that employs the similar research principles at the base level that are akin to studies that utilize primary data and involves steps that have to be followed in the same way as any research method [66].

The major sources of data are Government of India websites and reports such as the ones belonging to the Department of Heavy Industries, NITI Aayog Bureau of Energy Efficiency, public agencies such as Society of Manufacturers of Electric Vehicles (SMEV), Society of Indian Automobile Manufacturers (SIAM) and International Energy Agency, articles published by Bloomberg, Economic Times, Financial Times, reports by noted research agencies such as ICRA and scholarly articles published in journals available on public domain.

4. Data Analysis & Research Findings

Electric vehicles (EV) constitute a part of the new normal, the aftermath of the global pandemic, since the transportation sector across the world is undergoing a paradigm shift and displaying a unencumbered preference in favor of cleaner and greener vehicles [45].

4.1. Descriptive Statistics

As per the data available from the Society of Manufacturers of Electric Vehicles (SMEV), in financial year (FY) 2019-20 electric vehicle sales in India comprised of 3,400 electric cars and 1.52 lakh electric 2 wheelers. Unfortunately, due to Covid pandemic, only 25,735 units of high-speed electric two-wheelers were sold during Jan-Dec 2020, compared to 27,224 units sold during the corresponding period in the previous year [67].

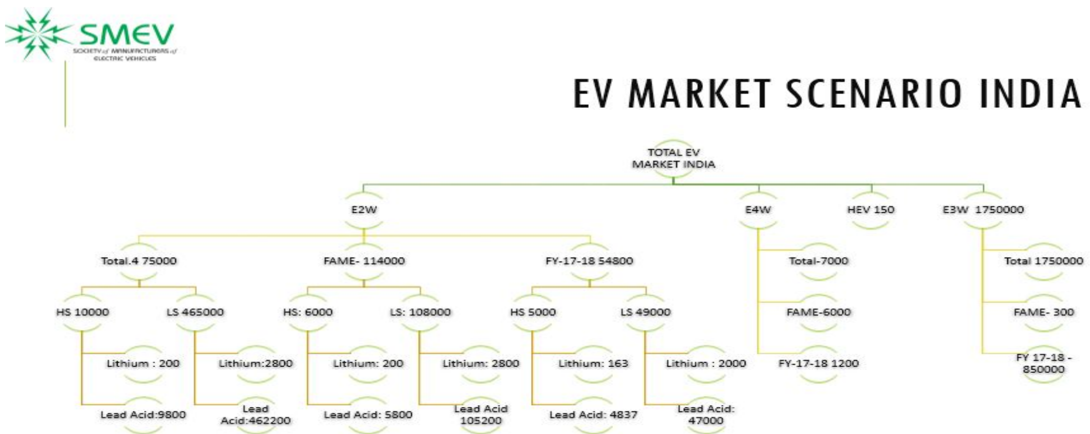

Figure 4: EV sales in India

The total EV sales grew by 20% in FY20 compared to the previous financial year.

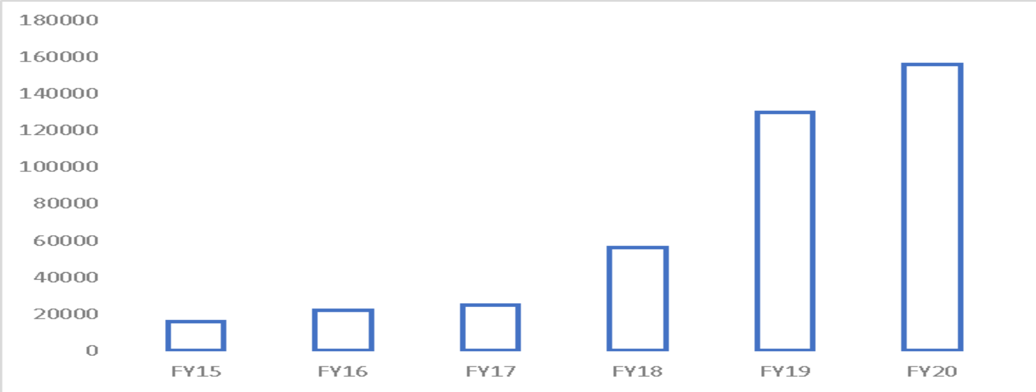

Figure 5: No of EV sold in India (except e-rickshaw)

However, presently EV penetration in India remains low despite the government initiatives [51]. The massive growth in two-wheeler sales has received a jolt partly due to the stringent requirements to be fulfilled by electric 2 wheelers for availing subsidy. The other major cause behind decline in vehicle sales is the COVID 19 pandemic.

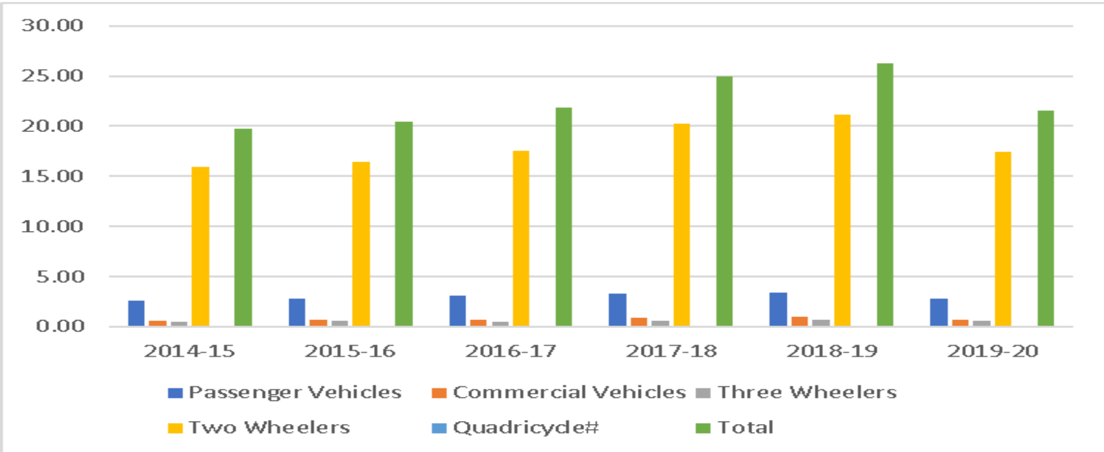

Figure 6: Automobile Domestic Sales Trends *[51]*

The lion's share (90%) of the car owners in India are geared up to change from ICE to electric vehicles, on condition that the opposite infrastructure is in position, as revealed by a survey carried out by the Economic Times in May 2019 [68]. However, presently EV market penetration in India stands dismally low at around 1% of overall vehicle sales made in India and 95% of EV sales is constituted by electric two-wheelers [68]. According to ICRA Ltd. (formerly Investment Information and Credit Rating Agency of India Limited), while sales of electric 2 wheelers registered a 21% year-on-year growth to 0.15 million units in the first year of scheme, 2019-20, the number of such vehicles that availed the subsidy provided under the FAME-II scheme plunged [69].

4.2. Consumer's Perspective

Of the 350 people interviewed for the survey, 294 or 84% feature in the age group 26-45 years having various professions, from students to businessmen, with only 3% of them residing in the rural areas (majority of whom either are neutral to technology or would never go for innovative technology). Our interest is in the rest 97% of the respondents in this age group.

As much as 53% of the respondents in the group of interest believe that in the next 2-5 years the majority of the cars owned in India will comprise of e-cars. 88% of the respondents believe that both driving sense and road infrastructure are key impediment in the adoption and implementation of new-technology. Range anxiety is the biggest consideration among the potential EV buyers. Among the 350 respondents of our survey, more than 24% have stated range anxiety to be their primary concern while environmental considerations rank second at 13.4%. 111 of the 350 respondents have rated inadequacy of charging station as their key concern. It's a fall out of range anxiety.

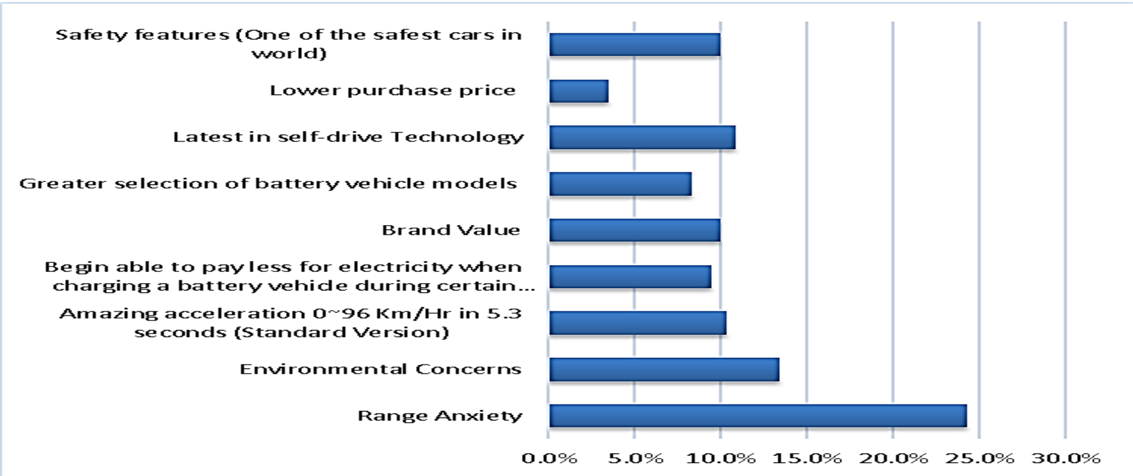

Figure 7: Key considerations among potential EV customers in India

More than half of the respondents say that the biggest concern behind owning a battery electric vehicle is the range anxiety and its obvious fall out is the inadequacy of charging infrastructure.

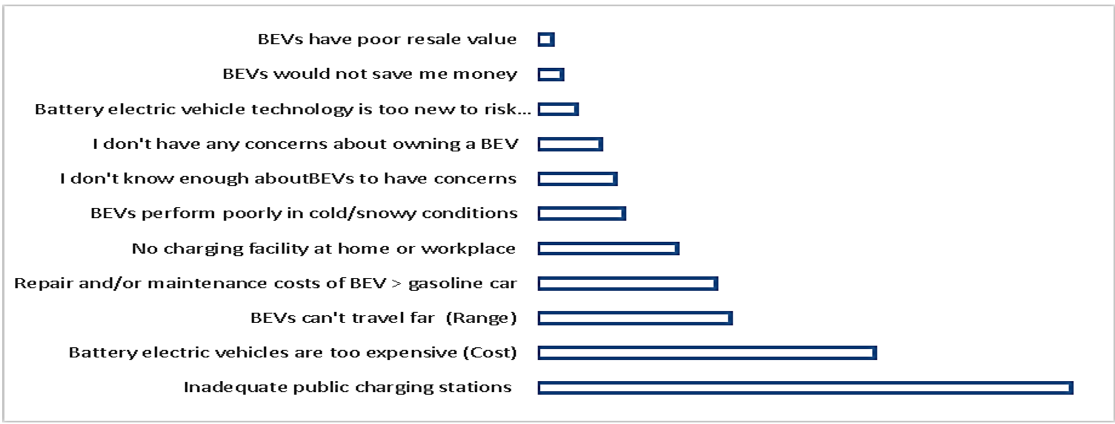

Figure 8: Top concerns among present and potential owners of BEVs

43% of the total respondents say that the government should work out policies that would ease the erection of EV charging stations in apartment buildings or other multifamily housing units and provide incentives for businesses and workplaces to install battery vehicle charging stations.

Table 1: Public policies or measures that would ease EV ownership

Public policies or measures	No. of Respondents	%
Make it easier to install battery vehicle charging stations in apartment buildings or other multifamily housing units	70	20
Encourage automakers to make some of their cars available as a battery model	16	5
Grant battery vehicle driver's access to high occupancy (HOV) lanes (dedicated lanes on roads)	24	7
Provide a tax credit or rebate for part of the vehicle purchase price	23	7
Provide incentives for businesses and workplaces to install battery vehicle charging stations	79	23
Provide more information about battery vehicles	35	10
Provide preferential parking sports for battery vehicle drivers in highly trafficked areas like sports arenas or universities	58	17
Reduce or eliminate tolls on roads, bridges, and tunnels for battery vehicle drivers	45	13
Total	350	100

It is obvious from the below (Table 2), 97% are likely to choose a pure BEV but amazingly battery recycling capability of the manufacturer is the key factor. influencing their choice of product and not battery capacity, ethical concerns feature lowest on the list.

Table 2: Customer Perception & Market Expansion

	Purchase Consideration				
How likely is the consumer to choose a pure BEV	Battery doesn't influence	Battery Capacity	Company's recycling capability	Ethical sources of raw material	Total
Very likely	53	47	72	37	209
Somewhat likely	41	24	42	23	130
Somewhat unlikely	1	2	4	2	9
Very Unlikely	0	0	1	1	2
Total	95	73	119	63	350

The key concern (Figure 9) behind adoption of e-mobility from the consumer's perspective is the lack of charging infrastructure followed by the cost of EVs compared to comparable models of ICE vehicles. Range anxiety comes a close third.

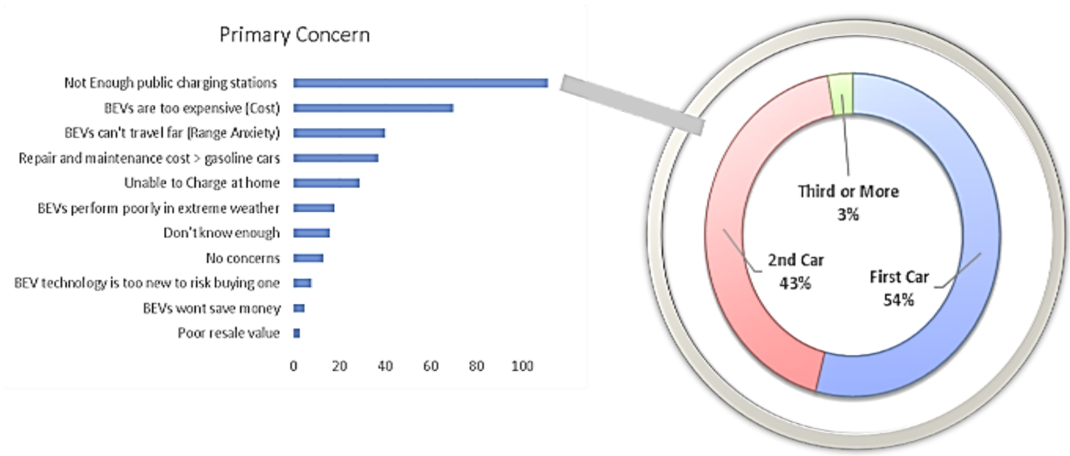

Figure 9: Key concerns of present / potential EV buyers

4.3. FAME and E-mobility adoption in India

The electric vehicles industry at a nascent stage in India. It is less than 1% of the total vehicle sales however has the potential to grow to more than 5% in a few years. At present there are more than 5 lac electric two-wheelers and few thousand electric cars on Indian roads. The industry volumes have been fluctuating, mostly depending on the incentives offered by the government [70], [71].

The Government of India implemented the Faster Adoption and Manufacturing of Hybrid and EV (FAME I) scheme in 2015 having an outlay of ₹ 8.95 billion (USD 130 million), that provided subsidies for 2-wheeler and 3-wheeler electric vehicles, hybrid vehicles and electricity driven cars and buses. FAME II, the scaled-up version of FAME I, has been effective since April 2019, with an outlay of ₹ 100 billion (USD 1.4 billion) that will be used for providing upfront incentives on the purchase of EVs (₹ 85.96 billion) and will also provide support during the deployment of charging infrastructure (₹ 10 billion) [72].

The legal regime in India that guides e-waste has undergone remarkable changes over time to reach its present state in which it has incorporated Extended Producer's Responsibility (EPR) and collection of e-waste. Huge amounts of battery waste generated by EVs have provided a unique opportunity for fostering a recycling industry within the country, which at present is only in a budding stage [45].

Table 3: FAME India Scheme - Phase II

Total Number of Vehicles Sold under Fame 2 Scheme (as of 30, December 2020)	41517
2 Wheelers	30885
3 Wheelers	9295
4 Wheelers	1337
No of Models	85
Incentive Amount (₹ billion)	1.3137

Source: Department of Heavy Industry, Government of India; National Automotive Board (NAB)

India has a vested interest in battery recycling as much of the Lithium-ion batteries used in EVs are imported from China which keeps the prices of EVs elevated. Battery recycling will bring down import bill besides making EVs cheaper. the battery accounts for 40% – 50% of the total cost of manufacturing an electric vehicle. India's lithium battery imports jumped 300% to 71.2 crore units and was worth $1.2 billion in FY19 compared to 17.5 crore units worth $384 million 2016-17 FY20 saw imports of 45 crore units that amounted to $929 million [73].

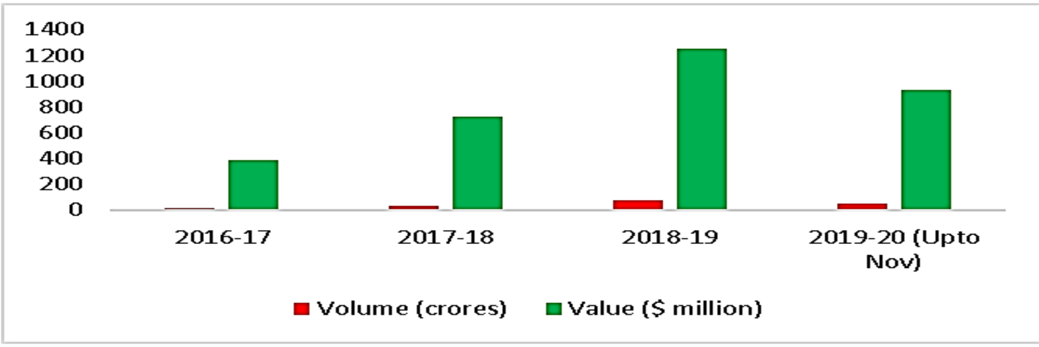

Figure 10: India's Lithium Battery Imports

The Indian EV industry is almost ready for take-off but for the incentives. It is expected that with FAME-2 the Industry may witness a quantum leap in volumes and technology. SMEV sees a great opportunity with EVs in reducing the carbon footprint, dependence on Crude oil imports, creating jobs and building a new technology knowledge center in India [70], [71]. According to announcements made by the government, under the second phase of FAME India Scheme, over 27,000 EVs have been supported till September 10 2020 through the use of demand incentives worth about ₹95 crore [54].

While the government continues to promote use of electric vehicles for waging war against the menace of pollution and reduce its crude oil import bill, India still lags seriously behind in terms of putting in place an authorized facility for recycling spent lithium batteries, that are the product of rigorous use of these batteries in electric vehicles [74], [75]. The requisite technologies for complete recycling of lithium batteries are already available, which is why the India government is concentrating on gathering the necessary funding for investing in such facilities [75].

The private sector too is mobilizing significant investment for manufacturing and installing electric vehicle supply equipment (EVSE) infrastructure throughout the country. This consist of both charging and battery swapping technologies. According to a recent report EV battery swapping market in India is anticipated to touch $6.1 million by 2030, recording 31.3% growth during 2020-2030 [76]. Both solutions are corroborated through innovation in business model that makes superior utilization of infrastructure possible [57]. The Indian Government plans to erect 69,000 EV charging kiosks, across fuel stations pan-India as a massive initiative to accelerate the adoption of EVs in the country.

According to the proposals received, the GoI has sanctioned 2,636 (public) charging stations to be spread over 62 cities across 24 states and Union Territories that would be installed by 19 public entities. Out of the sanctioned number, 1,633 stations will be fast charging while rest 1,003 will be slow charging stations. With this, approximately 20,000 charging points are expected to be installed across selected cities [54].

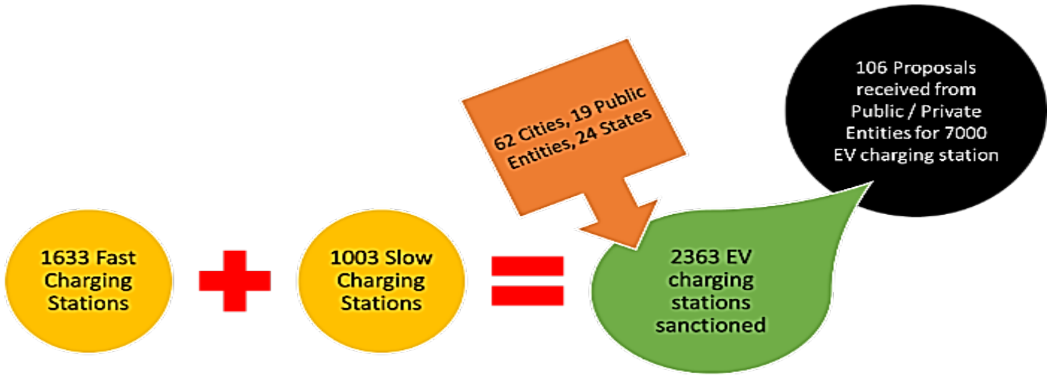

Figure 11: Charging Stations Sanctioned by GoI

4.4. Research Findings

In order to make sure and to that EVs penetrate vehicle markets rapidly and to enable faster penetration, a key obstacle that must be handled is the range anxiety - a fear that the vehicle will run out of electricity prior to reaching the next available charging station [3]. On an average people use their cars on a daily basis to attend work or social calls, and to do shopping and other regular outside works. Rarely any of these tasks will make a person travel any distance that is greater than 60 kilometers from their home. The availability of new electric vehicle models such as the Polestar 2 that can travel a distance of 400 to 500 kilometers for every charge, running out of fuel while travelling on wheels does not seem to be a big concern for potential EV buyers [30].

Unless the vehicle owner is taking the car out for a long road trip, range anxiety doesn't seem to be a real concern that can hinder e-mobility. But then again if a person has not been able to charge the car at regular interval and say he runs out of charge right on his way to office or shopping mall, or a theater or may be the doctors', he will be looking for a charging station nearby which is not so readily available at this point of time. Even the idea of going on a road trip is not that farfetched. However, on a road trip range anxiety becomes a real issue. The GoI's initiative towards establishment of charging kiosks at petrol pumps pan-India is believed to be able to address people's apprehensions about not finding a charging station at adequate intervals and hence, if implemented successfully, will be able to tackle the issue of range anxiety to a certain extent. In order to allow speedier adoption of EVs, the Indian government has published guidelines and standards for public charging infrastructure. Its FAME I and FAME II schemes have phased out plans that will enable the roll-out of public charging infrastructure. Cost of batteries is also a big concern for the owner and the battery price makes up a big part of the vehicle price. Recycling can be a plausible solution. It is also necessary to handle environmental concerns in terms of hazardous waste generation, effectively. That is a major reason why recycling of electric vehicle battery and its reuse has taken precedence for both car and battery manufacturers.

Plans to fuel EVs with clean power are in progress, with industry participants trying to explore the possibilities of combining solar and EV technologies in Mumbai and other cities [57]. Additionally, the Indian Railways has revealed its intention to hand out space for EV charging stations at the parking lots available at the stations. Railways authorities are intending to encourage and attract private sector participation through the issue of tenders for setting up this infrastructure [57]. Parking lots at the Nizamuddin and New Delhi railway stations in the Indian capital have already been identified for establishing EV charging spots. For this the Indian Railways has signed Memorandums of Understanding (MoU) with Department for International Development (DFID) under the UK government for technological support [77]. Several units from the Indian public sector have signed a number of MoUs with aggregators for the purpose of developing devoted EV charging stations across the cities in India [57].

Exicom Tele-Systems intends to recycle electric vehicle batteries that have reached the end of their lifecycle in order to manufacture and market custom battery packs that can be put to non-automotive applications for instance UPS used for commercial and industrial purposes, inverters used in residences, and renewable energy storage [75]. Tata Chemicals has commenced the commercial recovery of cathode active materials from used lithium-ion cells/batteries [78]. The government has been looking at different charging models with special attention to specific local conditions in order to kick-start quicker EV deployment. Accordingly, for developing India's EV industry, the GoI will also have to identify and accept ‘battery swapping’ to be a viable alternative to replace vehicle's direct charging technology. The process will be faster and easier. I will also address an issue that might turn into a big problem with the greater adoption of e-mobility – parking time. The EVs have to be parked for the duration of charging. That will also require added infrastructure development and will entail added cost for the vehicle owner besides being time consuming. None of the literature we discussed have drawn attention to this potential problem.

The Indian auto market being dominated by two and three-wheelers with over 80% of total vehicles in India falling in the two-wheeler category, inadequate EV charging infrastructure is a big issue. Under the circumstances, battery swapping technology may help the country witness a faster adoption of e-mobility in the electric two-wheeler and three-wheeler segment.

5. Conclusion & Recommendation

Adoption of e-mobility is becoming a necessity and is inevitable. The solution to handling toxic battery waste generation is creating a circular economy for EV batteries. The first step towards this direction is the expansion of our laws to embrace li-ion battery chemistries [45]. Lessons from China will assist the country in developing superior battery recycling policies and bringing down EV battery recycling prices. Additionally, subsequent use of battery will create opportunities for new business and employment developing in the automotive sector. Higher use of telematics will bring down range anxiety through the provision of driver information regarding the charge left and the distance that can be travelled with it, where the next charging station is located and accessibility and booking of that charging station when required.

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