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xEV Landscape in India and Future Trends

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Abstract: The electric and hybrid vehicles (xEVs) market in India is moving quickly due to enabling regulatory frameworks, ongoing technology developments and the preferences of buyers. It focuses on all the factors affecting India's progress in xEVs by examining trends in use, government schemes such as FAME and the benefits provided by each state. In 2024, sales of electric vehicles (EVs) in India surpassed 1.95 million units which was 27% higher than the previous year and experts estimate up to 30% of the four wheeler (4W) segment to be electrified by 2030 under supportive policies, more than double the expected number without such policies. A thorough PESTEL assessment determines the main factors that influence EVs such as more charging stations (the number increased 80 times since 2015), issues with obtaining batteries in sufficient quantities, the high price of EVs and how consumers' views are constantly shifting toward them. Artificial Intelligence and machine learning (AI/ML) methods are used to understand what is likely to drive the market and how government policies and infrastructure development are essential for promoting electrification. The report also analyzes battery improvement, declining battery prices and what emissions mean over the lifecycle, all of which give useful guidance for creating a greener environment for electric cars across India. Linking data with impact evaluation, the research gives a complete understanding of India's move toward electric vehicles and their impact on green transportation.

Keywords: xEV; FAME Scheme; Charging Infrastructure; AI/ML in EVs and EV Market

1. Introduction

EVs have been recognized as a pivotal solution for tackling global environmental challenges, urban air pollution, and energy security concerns. India's transition to EVs is gaining momentum, primarily because of the coincidence of government policies, technological developments, consumer preferences, and market dynamics. This introduction sets the stage for an in-depth exploration of India's xEV landscape, its growth trajectory, the challenges it faces, and the pivotal role of emerging technologies such as artificial intelligence (AI) and machine learning (ML).

The Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme has formed the backbone of India's EV strategy. Launched in 2015, FAME-I provided subsidies and incentives to the manufacturers as well as the consumers in the electric vehicles sector. With the following FAME-II, rolled out in 2019, the government expanded its focus to encompass charging infrastructure, public transportation, and localization of EV manufacturing. It is through this integration of financial incentives and a long-term vision that the policies have established a basis for growth and simultaneously addressed affordability and accessibility issues.

India's EV market has seen a gradual evolution in the last decade. Starting from two-wheelers (2W) and e-rickshaws, the sector now covers passenger cars, buses, and commercial vehicles. As per reports from the industry, there has been exponential growth in sales of EVs in the country, particularly with the urban centers experiencing

an enormous rise. Domestic players along with partnerships with global firms have added much strength to the market. Despite all these, India's EV penetration remains very modest compared with the rest of the world.

The adoption of EVs significantly highlights their environmental benefits. Specifically urban areas in India are dealing with severe air quality problems, and transport is a major source of greenhouse gases (GHG) emissions. Transitioning to EVs will reduce tailpipe emissions, improve the quality of urban air, and assist the country in meeting its climate obligations under the Paris Agreement. However, the environmental advantages of EVs are contingent upon the electricity sources used for charging, as grid reliance on fossil fuels can offset their emissions savings. Maximizing sustainability in the ecosystem of electric vehicles will depend on its strong integration of renewable sources into the electricity grid.

Consumer attitudes play a significant role in determining the adoption curve of EVs. Though early adopters have been embracing EVs for their environment-friendliness and lower operating costs, the mainstream consumer is remain unconvinced. Some of the major reasons for this concern are range anxiety, upfront cost of EVs is somewhat high, and limited charging infrastructure. But with increasing awareness campaigns, financial incentives, and entry of low-cost EV models, it is slowly bridging that gap. Consumer requirements, which must be systematically addressed in speeding adoption.

Despite the promising potential of EVs, several challenges the country still has to confront for the overall adoption process is the case. For example, high cost of the batteries and lack of sufficient charging infrastructure and imported component dependency will be crucial ones. The lack of skilled labour and constraints in R&D capabilities further hurt the industry's growth. All stakeholders such as suppliers, academicians, consultants, Battery Electric Vehicle (BEV) owners, potential customers, and government officials must collaborate to address these barriers and create a conducive ecosystem for EVs.

The Indian EV market is very diversified in nature, as different sections cater to different needs: urban and rural. The 2W leads the market mainly due to affordability and user-friendliness, while electric buses are gaining popularity for public transport. There is also commercial fleet operator interest in going electric to minimize operational costs. Financing options, government subsidies, and private-sector investments have only fueled this growth. However, to maintain the trend, competition must be encouraged and local production must be promoted.

AI and ML applications such as battery optimization, predictive maintenance, and route planning are the emerging intelligent solutions for a smarter, more efficient electric vehicle landscape. The applications of AI in India enable manufacturers to design vehicles that can meet varied customer needs, and ML algorithms help predict consumer demand while streamlining production processes. A significant advancement toward data-driven adaptive ecosystems has arrived through AI/ML in EV systems.

Charging infrastructure is the spine of the EV revolution. In India, the inadequate availability of public charging stations continues, especially in rural and semi-urban areas. There have been some developments in urban areas where fast chargers are installed and charging hubs have come up. Issues of dependency on the grid, high cost of installation, and lack of standardization continue to exist. Solutions like battery swapping, renewable energy-powered stations, and public-private partnerships are some of the emerging ways of bridging this gap.

This paper takes a closer look at the xEV landscape in India, analyzing government policies, techno-logical advancements, market dynamics, and consumer perspectives. Case studies and review of literature form an overall analysis of factors influencing the electric mobility future in India. By identifying the opportunities and challenges, this study shall be able to contribute to the discourse on sustainable transportation and form a roadmap for the attainment of India's EV aspirations.

2. Literature Review

2.1. Methodology

This review was conducted by looking in Scopus, IEEE Xplore and Google Scholar for studies on aspects of India's EV market, where keywords used were "Electric Vehicles India," "EV Policy," "FAME India," "EV Infrastructure," and "AI/ML in the EV Market India." A timeframe of 2015 to 2024 was selected to guarantee that the information remained recent and pertinent. Studies that focused purely on technical elements without addressing policy or market implications were excluded. From an initial pool of 120 articles, duplicates were removed and abstracts screened, resulting in 51 studies and 13 additional sources from automotive and Indian government databases

being selected for full-text review and thematic analysis.

2.2. EV Market Evolution and Trends

The EV market in India has seen rapid growth over the last ten years and in 2024, as shown in **Figure 1**, sales totaled 1.95 million, a 27% increase over the previous year [1,2]. **Table 1** reveals that 2Ws hold a share of 59.5%, three wheelers a share of 35.7% and 4Ws a share of 4.64%. The reasons for this growth include more renewable energy and the use of new financial systems [3,4].

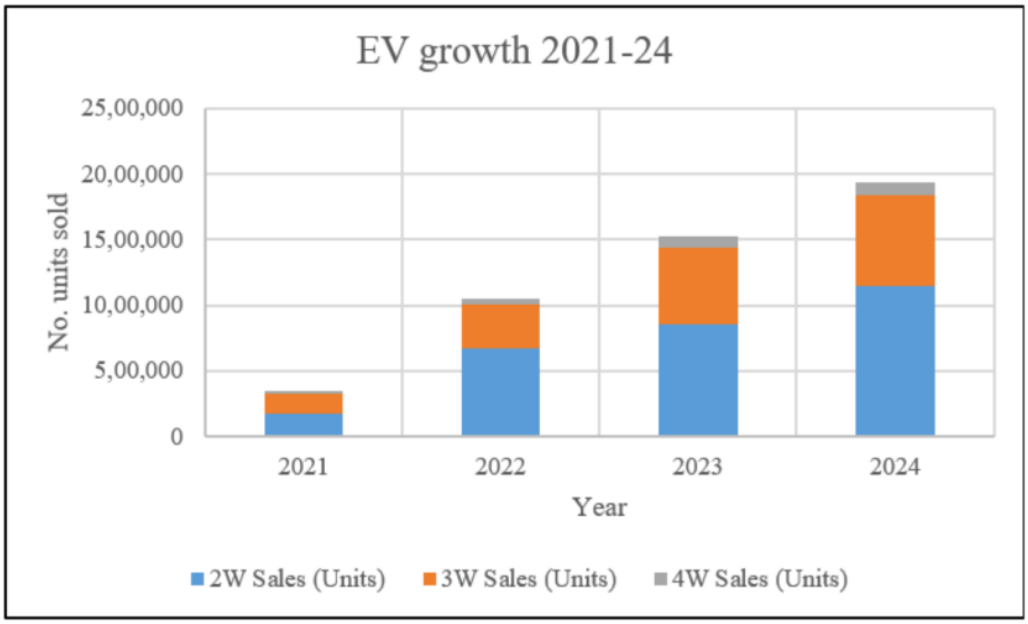

Figure 1. EV Market Growth Trends (2021–2024) [5].

Table 1. EV Sales Bifurcation 2024.

Types	Units sold	EV market share
2W	1,150,000	59.5%
3W	691,302	35.7%
4W	89,765	4.64%

2.3. Policy and Regulatory Frameworks

Adoption of electric vehicles in India has greatly benefited from government policies. As a result of FAME-I and FAME-II, more people were encouraged to buy electric vehicles as demand-side subsidies and infrastructure were introduced [7]. It is suggested from similar studies that India could make use of world-class practices in offering incentives and designing infrastructure [8,9]. Authors have also expressed views that a fast upsurge in electric cars can cause more e-waste and urge strict recycling laws [10].

2.4. Infrastructure and Regional Disparities

A significant challenge in India's EV adoption is the lack of a robust and evenly distributed charging infrastructure [11,12]. This study later also illustrates the zonal distribution of charging infrastructure in 2024, showing Maharashtra and Karnataka as leaders, while the Eastern zone lags behind. Such disparities highlight the need for region-specific strategies to support EV adoption [13,14].

Additionally, studies emphasize the importance of safety regulations to address India's diverse climate and lower operational expenses [15,16]. Research maximizing the use of charging stations through optimal location planning [17,18].

2.5. Environmental and Lifecycle Emissions

In urban areas, EVs greatly influence the environment and replacing gasoline-powered vehicles with EVs cuts down on greenhouse gas emissions [19]. Yet, how clean or sustainable EVs are depends greatly on the source of their electricity for charging and what materials were used to manufacture them [20,21]. A comparison of the life cycles shows that Battery Electric Vehicles (BEVs) tend to release less carbon emissions than Fuel Cell Electric Vehicles (FCEVs) in India because of the existing grid mix [22].

2.6. Consumer Perception and Social Factors

Consumer perception plays a vital role in EV adoption. Range anxiety remains a strong psychological barrier owing to sparse charging facilities [23,24]. Owing to these fears, government policies and technological progress are pushing demand [25,26]. Research highlights the intervening function of consumer attitudes in EV adoption, wherein favorable attitudes have a strong bearing on purchase behavior [27] Social factors, including peer influence, environmental awareness, and perceived economic benefits, also play a crucial role in shaping EV adoption trends, highlighting the need for targeted awareness campaigns and policy interventions [28]. While some also indicate that a synergistic approach incorporating policymakers, business stakeholders, and consumers is crucial for sustained long-term market growth [29,30]. The primary challenges are upfront costs, poor charging infrastructure, and standardization problems [31]. Innovative options like shared mobility models can minimize economic hurdles [32,33]. Furthermore, electric drive system advancements and local production are required to break through technological limitations [34,35].

2.7. Technological Innovations and AI/ML Applications

Energy management optimization and predictive maintenance in the EV sector are being made possible through AI and ML [36,37]. Big data analytics have advanced due to the launch of urban EV adoption services and management of traffic jams [38,39]. A review of the influence on manufacturers, policymakers and the energy sector showed that more infrastructure, skilled workforce changes and better policies are needed [40]. To analyze how markets develop and the relationships between elements, people have used Interpretive Structural Modeling (ISM) and Cross-impact matrix multiplication applied to classification analysis (MICMAC) [41,42].

2.8. Gaps and Synthesis

Despite this comprehensive overview, there is a clear gap in analyzing regional differences in EV adoption across India. Information on national trends and policies is usually available, but there is a shortage of scientific research on how differences in laws, economic gaps and infrastructure affect the North, South, East and West regions. This oversight limits the nuanced understanding necessary for targeted interventions.

3. Types of EVs

Building on the insights from the literature review, it is evident that the development of the Indian electric vehicle market is influenced by the different categories of EVs, which have their distinct features and prospects. The development of Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs), Range-Extended Electric Vehicles (REEVs), and FCEVs provides various paths for expansion, based on technological progress, market needs, and policy incentives. This section examines these various forms of EVs, their current status and future, and how they fit into the context of India's electrification ambition. By knowing these categories of vehicles, we can determine their place in the larger scheme of India's EV adoption path.

3.1. Plug-in Hybrid Electric Vehicle

A PHEV integrates an internal combustion engine (ICE) with an electric motor and a bigger battery than standard hybrids. It can travel in pure electric mode for a short distance before reverting to the ICE, providing a compromise between fuel economy and lower emissions, configuration for the same is evident in **Figure 2**. PHEVs are flexible since they can be plugged into an external power supply but fall back on gasoline or diesel for use when necessary, making them a convenient transition technology between conventional and fully electric vehicles.

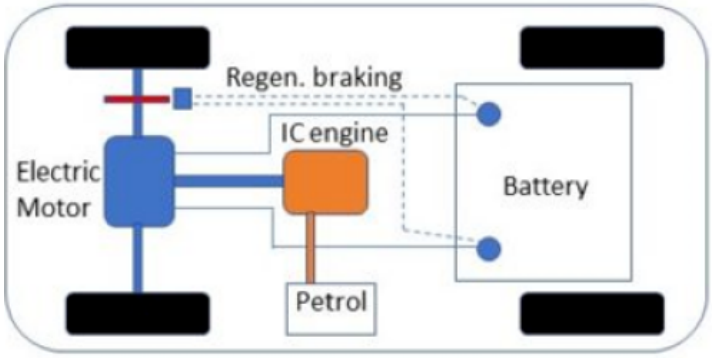

Figure 2. PHEV-Architecture.

- PHEVs are projected to grow at a CAGR exceeding 105% over the forecast period.
- Major automotive manufacturers in India, such have established PHEV models in international markets.
- PHEVs feature a more powerful electric motor and a significantly larger battery compared to conventional hybrid vehicles.
- These vehicles offer a practical and adaptable mobility solution, combining the benefits of electric and internal combustion engine (ICE) powertrains.
- High costs of both internal combustion engines (ICE) and batteries, coupled with the absence of government incentives or tax benefits, limit PHEV adoption in India, making available models prohibitively expensive.

3.2. Battery Electric Vehicle

A BEV is a battery-powered car that uses an electric motor as the sole means of propulsion and does not include an internal combustion engine, illustrated in **Figure 3**. BEVs depend on external charging stations and generally feature a range of varying length based on battery capacity. With no tailpipe emissions and reduced running costs over time, they can play an important role in minimising carbon footprints. However, their widespread adoption is dependent on the availability of charging stations and advancements in battery technology.

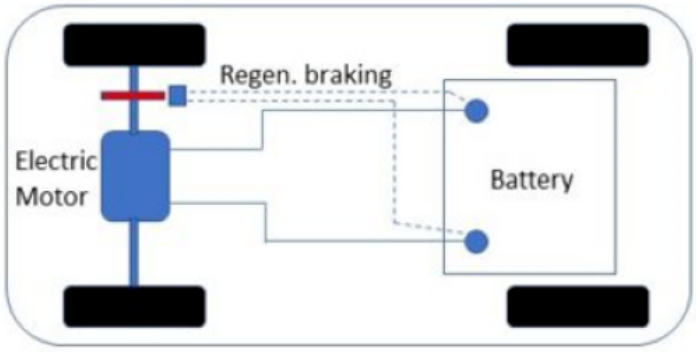

Figure 3. BEV-Architecture.

- BEV accounted for 96% of the total revenue share in 2020.
- Government policies and regulations favor the adoption of BEVs through incentives and emission norms.
- Climatic conditions and stringent CO_2 regulations drive the transition towards BEVs.
- BEVs offer a lower total cost of ownership (TCO) in the long run compared to internal combustion engine (ICE) vehicles.
- Technological advancements in battery systems and the declining cost of lithium-ion batteries enhance the affordability and efficiency of BEVs.

3.3. Fuel Cell Electric Vehicle

A FCEV produces electricity from hydrogen fuel cells, in which hydrogen reacts with oxygen to generate electricity while releasing only water vapor as waste, illustrated in **Figure 4**. In contrast to BEVs, which pre-store electricity in batteries, FCEVs drive electricity on-site, providing improved range and a quicker refilling time. In spite of these benefits, FCEVs are not yet widely adopted because of the cost of fuel cell technology and a lack of hydrogen refueling infrastructure However, ongoing research and policy support aim to expand their viability in the coming years.

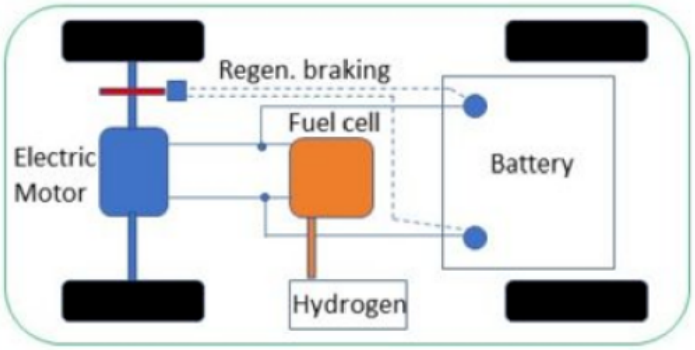

Figure 4. FCEV-Architecture.

- India successfully tested its first hydrogen FCEV with a range of 250 km/kg.
- The Union Ministry for Road Transport and Highways, in collaboration with an OEM and launched India's first hydrogen-powered FCEV project.
- India aims to develop green hydrogen infrastructure, launch hydrogen-powered buses (Delhi to Jaipur), and export 70% of green hydrogen by 2030. The mission is structured in four phases under the NHEM Policy (2021).
- Lack of production, distribution, and storage infrastructure, high fuel cell technology costs, and limited public awareness hinder FCEV adoption.

3.4. Range-Extended Electric Vehicle

A REEV is an electric vehicle equipped with a small internal combustion engine that acts solely as a generator to recharge the battery when it depletes, rather than directly driving the wheels, the configuration for the same is illustrated in **Figure 5**. This design helps mitigate range anxiety while maintaining the benefits of an electric powertrain. REEVs offer an efficient solution by reducing dependence on large battery packs, making them a more cost-effective alternative to BEVs while still supporting the transition toward full electrification.

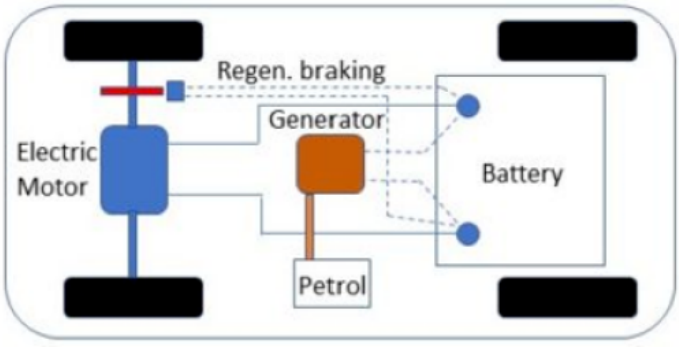

Figure 5. REEV-Architecture.

OEMs are actively studying and addressing range anxiety and consumer perception, particularly in relation to

Range-Extended Electric Vehicles (REEVs), to mark and support the ongoing shift in electric vehicle adoption across India.

3.5. Lifecycle Emissions Comparison: BEVs vs. FCEVs

While tailpipe pollution from both BEVs and FCEVs is zero, their whole lifecycle emissions vary a lot, mainly due to how things are powered in India today. India's electricity grid for BEVs is mostly run with fossil fuels, mainly from coal. Naturally, their upstream emissions linked to energy production can increase a lot unless they make use of more renewable sources.

FCEVs use hydrogen instead and their operation produces water, yet the bulk of hydrogen production comes from steam methane reforming (SMR), a process that produces a lot of carbon. Adopting green hydrogen as electricity for making FCEVs may still not lead to big carbon savings compared with BEVs.

As a result of the study by the research [19, 22], BEVs produce less pollution in their life cycle than FCEVs in India. Nevertheless, the situation might change such that FCEVs benefit more when green hydrogen facilities grow and the grid becomes cleaner. For this reason, setting future electrification strategies must include life cycle assessments (LCAs) to guarantee that carbon neutrality is achieved.

4. Government Policies

The Indian government has played a proactive role in promoting EV adoption as can been in **Table 2**, implementing a series of policies aimed at accelerating market growth, improving infrastructure, and reducing upfront costs. Among these initiatives, the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme has been instrumental in shaping the EV landscape.

FAME-I, initiated in 2015, gave demand-side subsidies to promote the sale of electric and hybrid vehicles, giving fiscal incentives to both producers and buyers. Based on its success, FAME-II, launched in 2019, widened the scope to incorporate local manufacturing, electrification of public transport, and development of charging infrastructure. This change reflected a shift from direct subsidy to a broader policy initiative towards the development of a self-sustaining EV ecosystem.

These initiatives by the government are an indication of a long-term policy to synchronize EV adoption with domestic sustainability objectives alongside solving issues surrounding affordability, infrastructure, and production localization.

Goals and Benefits of EV Policies

The EV policy framework in India is designed to align with long-term sustainability and economic goals. These include:

Goals:

- Attract major global EV manufacturers, such as Tesla, to set up manufacturing units in India.
- Promote indigenous manufacturing and align with the 'Make in India' campaign.
- Reduce dependency on crude oil imports and narrow the trade deficit.
- Contribute to India's climate goals by reducing emissions intensity by 45% by 2030 and achieving net-zero emissions by 2070.
- Improve public health by reducing air pollution.

Benefits:

- Stimulates innovation and progress in EV technology.
- Enhances local manufacturing capacities.
- Positive environmental impact by reducing air pollution.
- Economic growth through increased investment and reduced import bills.

Key Features

The EV policy framework incorporates several incentives and requirements, as outlined below:

- Import Duty Concessions: Reduced customs/import duty of 15% on EVs priced USD 35,000 and more for 5 years, subject to firms investing not less than USD 500 million (Rs. 4,150 crore).
- Domestic Value Addition (DVA): Minimum DVA of 25% in 3 years and 50% in 5 years.
- Investment Requirements: Create plant and machinery, charging infrastructure, and other assets; royalty payments are not considered investment.
- Bank Guarantee: Refunded on reaching 50% DVA and the amount of investment or investment required or duty foregone in 5 years, whichever is greater.

Probable Impact

The combined objectives and provisions of the EV policy are likely to have the following effects:

- Attracting Global Players: Addresses the needs of international EV producers such as Tesla for tariff relief and promotes foreign investment in India's EV industry.
- Market Growth: Makes India a value player in the world EV market and positions the automotive industry as a key contributor to India's GDP.
- Environmental and Health Benefits: Decreases air pollution, aids in national climate objectives, and enhances public health by minimizing vehicular emissions.

Summary of Policies and Milestones

The development of India's EV policy landscape, as elaborated above, is presented in **Table 2**. These policies constitute an all-encompassing strategy for resolving challenges and leveraging opportunities in the EV ecosystem. While policy intervention has played a pivotal role in India's EV transformation, success with these measures also depends on infrastructure preparedness and technological advancements.

Table 2. Policies and Initiatives Supporting Electric Mobility in India [43].

Year	Ministry/Organization	Policy/Initiative
2011	MNRE	Alternate Fuel for Surface Transportation Programme
2013	DHI	National Electric Mobility Mission Plan (NEMMP)
2015	DHI	FAME India Scheme Phase 1
2018	MoRTH	Green License Plates
2018	MoF	GST Reduction on Lithiumion Batteries
2018	MoP	Delicensing of Setting Up of Charging Stations
2019	MoP	Grid Connectivity Safety Regulations
2019	DHI & NITI Aayog	National Mission on Transformative Mobility and Battery Storage
2019	MoRTH	Advised States to Minimize Road Tax on EVs and License for Ages 16–18 for EVs
2019	MoHUA	Amendments in Model Building Bye-laws (MBBL 2016) for EV Charging Infrastructure
2020	MoRTH	Sale and Registration of EVs Without Batteries
2020	MoF	Income Tax Deduction for Purchase of EVs (Section 80EEB)
2020	MoP	Electricity Consumer Rules
2021	MoRTH	Wayside Amenity with EV Charging Stations Along Highways
2021	DHI	National Programme on Advanced Chemistry Cell (ACC) Battery Storage
2021	DHI	Amendment in Subsidy for E2W under FAME-II
2022	MoP	Revised Guidelines and Standards for Charging Infrastructure
2022	MoP	Revised Guidelines on Prepaid Collection of Service Charges
2022	MoP	Provision for Public Charging Infrastructure in Revamped Distribution Sector Scheme
2023	MoP	Revised Guidelines on Ceiling Limits for Capital Expenditure
2023	CEA	Additional Safety Requirements for EV Charging Stations
2023	MoHUA	PM E-Bus Sewa Scheme
2024	MHI	E-Mobility Promotion Scheme
2024	MHI	Scheme to Promote Manufacturing of Electric Passenger Cars

4.1. Charging Infrastructure

The establishment of a strong charging infrastructure is one of the most significant facilitators of EV uptake in India. Although there is growing interest in EVs, a poorly distributed and underdeveloped charging network continues to be one of the greatest barriers to mass adoption. Government efforts and private investment are collectively striving to extend the national charging network.

Progress in building public EV charging facilities can be seen in different parts of India. By looking at **Figure 6**, you can see that the presented data is the number of public charging stations divided by zone (ICCT, 2024). If you look at the growth between 2023 and 2024, you can clearly see more development in the West and North of the

world. In 2024, Maharashtra had over 3,000 charging stations and Karnataka reached 1,022—showing how both states are strongly committed to EV infrastructure. Delhi contributed to the observed growth in India. Meanwhile, the Eastern zone is falling behind and shows that more policy effort and private sector action are required in that area.

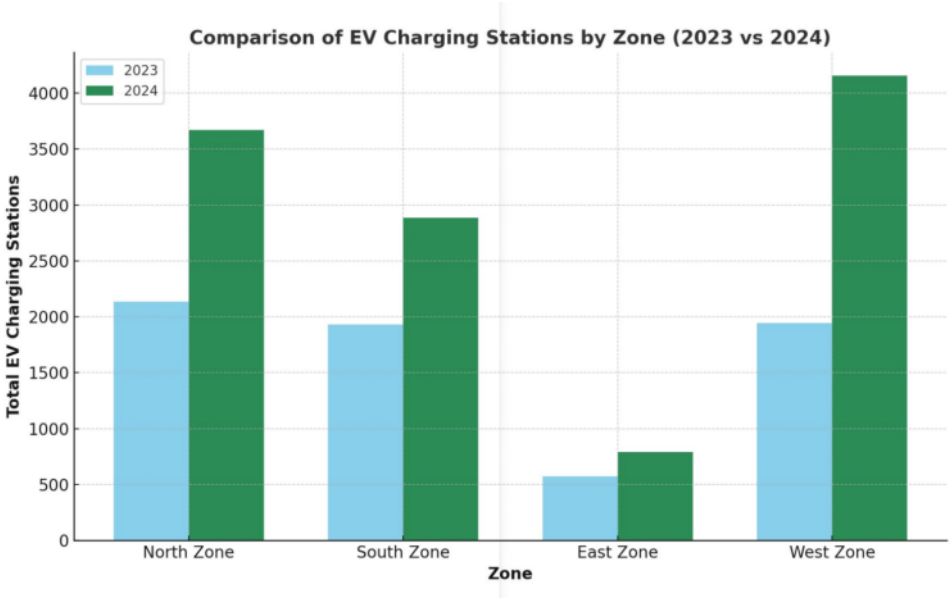

Figure 6. Zonal Distribution of Charging Infrastructure. Source: ICCT, 2024 [44].

The reason Maharashtra is ahead in EV infrastructure is because of positive policy actions, a lot of demand in cities and effective public teamwork. Under the EV policy, the state government offers incentives for creating charging stations, requires buildings meet EV standards in their bylaws and requires that public transports be switched to electric vehicles. Low-emission zones were created in Mumbai and Pune with government support for EVs which other states are now following.

On the other hand, some regions in the East and Central India which are considered underserved, need specific strategies. Electric fleets can be charged flexibly by using battery swapping stations and mobile charging units that avoid the issues caused by the grid and land shortage. The market for battery solutions as a service (BaaS) is increasing in mid-sized cities and solar-powered vans run by startups are now supporting rural electrification efforts. Given proper support such models may help people in less developed areas embrace EVs and build equity across the country.

Even with these developments, a number of challenges persist. Building an excellent, available charging infrastructure is still a multifaceted challenge, demanding attention to safety, economic viability, location planning, and standardization. The concerns are to be addressed through a combination of policy intervention, technological development, and strategic investments, which will be essential for the long-term sustainability of India's EV system.

4.2. Policy Effectiveness Evaluation

FAME-I and FAME-II have clearly helped since India sold more than 1.95 million EVs in 2024 which marks a 27% increase over the previous year. Especially, the 2W and three-wheeler (3W) groups have experienced rapid growth due to incentives and support offered by the government. However, FAME-II had the goal of installing 46,000 charging stations, but at present only half of this number or around 20,000, have been set up which indicates a problem with implementation. In any case, government policies have helped move the Indian battery manufacturing industry and draw attention from global OEMs, showing the policies have played their part in advancing India's electrification plans.

5. Market Dynamics and Consumer Behavior

Knowledge of customer attitudes and market forces is important for driving the transition to electric vehicles (EVs) in India. Consumer behavior and choice are largely driven by cost, convenience, and range dependability—issues that have a decisive impact on buying choices.

Globally, the market for EVs has experienced active fluctuations, with China taking the lead in 2024 by representing 61% of overall 4W EV sales, followed by Europe (20%) and the USA (10%). Interestingly, India has also made a significant mark, representing 50% of the remaining global sales, which is an indication of its increasing influence in the international EV scenario.

In India, the 2W EV category remains the trendsetter, the market leader garnering 425,600 units, while its second-largest contender achieved 234,111 units, about half the leader's sales. Within the 4W EV category, OEM A was top with 61,565 units sold, even though this showed a 6% drop over 2023. OEM B, however, showed remarkable progress, achieving 21,966 units sold, an 85% year-on-year growth.

Despite strong sales growth as depicted in **Figure 7**, consumer reluctance is still a hindrance. Range anxiety, or the fear of exhausting charge before arriving at a charging point, is one of the strongest psychological deterrents to EV adoption in India. This is further compounded by insufficient charging infrastructure and limited battery capacity, both of which lead to lower consumer confidence in EV dependability.

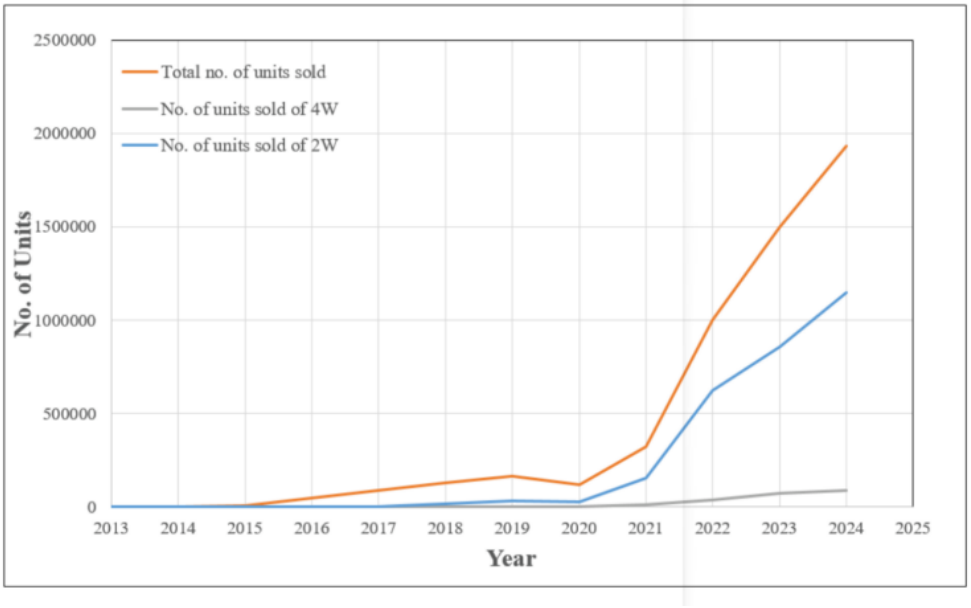

Figure 7. 2W vs. 4W Growth in Last 12 Years. Source: SIAM, 2024 [45].

Meanwhile, India's EV sector is rapidly changing, fueled by changing trends and future expectations. In 2023, India outpaced China in three-wheeler EV sales, clocking 580,000 units against China's 320,000 [46]. This segment contributed 38% of all EVs sold in India, highlighting the role of commercial EV uptake in India's electrification process. In the PV industry, 92,344 BEVs and 82,606 HEVs were sold in 2023, accounting for 2.3% and 2% of total PV sales, respectively. BEV sales, though, declined in the latter part of the year because of pricing gaps as well as taxation differentials.

One of the primary drivers of this change is the taxation framework, wherein BEVs are favored with an incentivized 5% GST rate, averaging at INR 15.4 lakh, while HEVs are subject to the 43% GST slab, averaging INR 25.1 lakh—a mere difference of 10% in price that impacts consumer behavior.

In the 4W BEV segment, OEM A retained its leadership with a 72% market share, while OEMs B and others made significant inroads. But 2024 was a watershed year, with OEM B significantly improving its market position.

As illustrated in **Figure 8**, and based on total passenger EV sales data from SIAM [45], OEM B achieved a 33% EV sales penetration during the first half of 2024. In November alone, electric vehicles accounted for 70% of its overall

vehicle sales. Notably, the company's newly launched EV model became India's top-selling electric passenger vehicle for two consecutive months—recording sales of 3,116 units in October and 3,144 units in November—capturing over 30% of the monthly EV market share during this period.

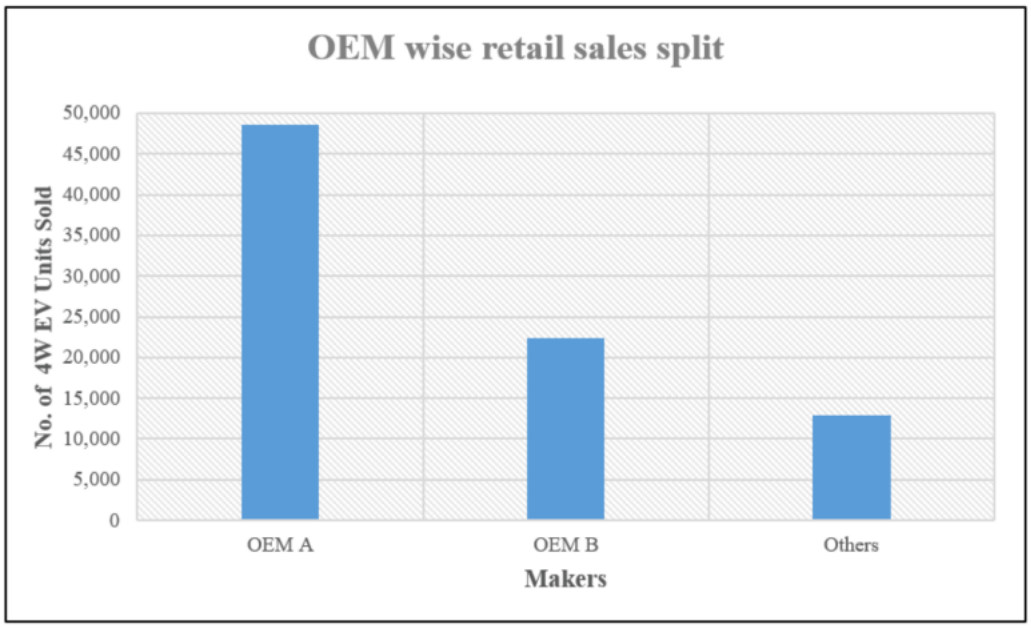

Figure 8. OEM Wise Market Split of 4W in 2024. Source: SIAM, 2024 [45].

By comparison, OEM A experienced a decline in market share, from 73% in 2023 to 62% in 2024, even while holding its leadership ranking. These movements underscore the more competitive environment for India's EV industry, in which new players are gaining share by pursuing agressive growth and targeted product introduction.

The growth of India's EV industry exhibits an intricate convergence of government push, investment from the private sector, and consumption trends among the people. Sustained long-term growth calls for linking customer-centric efforts to wider market interests such that the aggregate inputs from infrastructure, policymaker support, and product R&D synergize into a healthier and more resilient EV industry.

6. PESTEL Analysis

Gathering information about the Indian EV industry can be done by using the PESTEL method and it helps in spotting what both supports and obstructs the industry's growth.

Political

India's EV policy ecosystem, including FAME-II and state-level incentives, prices for EVs have dropped by 25% or even more for 2Ws and 15–20% for 4Ws [47]. Moreover, certain government actions like charging only 5% GST on EVs offer huge financial help [48].

Economic

Battery costs in India have dropped from INR 25,000/kWh in 2010 to INR 6,000–8,000/kWh by 2024, a reduction of ≃70% [49]. Fuel prices for petrol have surged to INR 105 per litre (2024), further making EVs' total cost of ownership much lower by an estimated 30–40% over the next ten years [50].

Social

A 2023 survey by [51] showed that over 50% of urban consumers are willing to consider EVs for their next vehicle purchase, driven by cost savings and environmental concerns. Shared mobility (like e-rickshaws) grew by 20% year-on-year in 2023–2024, further boosting acceptance.

Technological

EV range improvements (average 250–400 km for 4Ws as of 2024) have addressed range anxiety to an extent. AI/ML tools (like energy management systems) have improved battery lifes-pan by 10–15% [52]. Public charging

stations have grown from 250 in 2015 to over 20,000 in 2024, a nearly 80-fold increase [53].

Environmental

Using the present Indian grid for BEVs already cuts down on total GHGs from vehicles by 30–40% which could get even better as the grid uses more renewable resources [54]. However, recycling of batteries is still a worry because only a little over ten percent of lithium-ion batteries get recycled in our country [55].

Legal

According to the Battery Waste Management Rules (2022) requires Extended Produced Responsibility (EPR) manufacturers to ensure end-of-life recycling and proper disposal. Legal frameworks also mandate data protection for connected EVs under India's Digital Personal Data Protection Act (2023), ensuring cybersecurity and privacy [56].

Considering all these issues in depth can allow the EV market in India to thrive and reach worldwide sustainability benchmarks.

7. Projected EV Market Factors in India

India is moving toward EVs because of several trends like the expansion of charging stations, the price increase of battery technology and changes in fuel prices. Maharashtra, Karnataka and Delhi have about 60% of the public charging stations across the country and the North-East, Jharkhand and Bihar have much less. The absence of common EV frameworks highlights why different states should make detailed plans: Maharashtra provided incentives of 15 percent for charging stations, meanwhile several eastern states have yet to finalize their EV roadmaps. In rural regions, mass adoption may hinge more on battery swapping and solar-powered mobile charging solutions than on urban fast-chargers.

These help to determine the vehicle preferences among consumers and the chances of replacing ICE vehicles with electric ones. In this part, the trends of these groups are examined, data forecasts are given and their roles in EV growth in India are analyzed.

Forecasts leverage logistic growth models for EV uptake, exponential trends for charging infrastructure development, and cost trajectory models for batteries and fuel prices. Such projections help inform how policy interventions and market forces could shape India's EV landscape.

7.1. Fuel Price Trends and Their Impact on EV Affordability

The cost-effectiveness of EVs over ICE vehicles is greatly dependent on fuel prices. In the last ten years, petrol and diesel have experienced consistent price hikes in India, increasing the cost of operating traditional fuel-powered vehicles. The average price of petrol as of 2024 stands at INR 105.18 per litre, and diesel at INR 92.73 per litre. In comparison, the cost of electricity used to charge EVs continues to be much lower, enhancing the cost-effectiveness of electric mobility even further.

Future estimates are for ongoing uncertainty in fuel costs based on the global shortage of crude oil supply, geopolitics, and a rise in carbon taxation. The trend will continue to propel buyers towards low-cost alternatives like EVs, especially as the price of batteries reduces.

7.2. Battery Cost Reductions and Their Role in EV Penetration

Battery prices continue to be a decisive factor in the affordability of EVs since they contribute significantly to an electric vehicle's overall production cost. In 2010, the cost of the battery in India was around INR 25,000–30,000 per kWh and continuously decreased to INR 22,000–25,000 in 2012, INR 18,000–20,000 in 2014, and INR 15,000–17,000 in 2016. The downtrend continued with battery prices dropping to INR 12,000–14,000 per kWh in 2018, INR 10,000–12,000 in 2020, and an estimated INR 6,000–8,000 in 2024.

Cost reduction by adoption of solid-state batteries and second-generation lithium-ion options could happen further, aligning EV costs with ICE models even without government subsidies.

7.3. EV Charging Infrastructure Growth

A strong charging network is central to the mass market penetration of EVs. India, as of 2015, had around 250 charging points, which steadily climbed to 500 in 2016, 1,000 in 2017, and 2,000 in 2018. With more policy support and investment by the private sector, charging points increased further to 3,500 in 2019, 5,000 in 2020,

and 7,000 in 2021. The estimated number in 2024 is around 20,000 charging points with ambitious plans from the government under FAME-II to roll out 46,000 more charging points throughout the nation.

Looking forward, India's EV plan projects a 1:20 ratio of charging points to EVs by 2030, following global best practices to counter range anxiety and enable higher adoption. The estimated exponential growth in charging infrastructure indicates robust policy support and increasing market confidence in electrification.

7.4. AI/ML Forecasting Techniques

For estimating trends in EV adoption, growth of charging stations and drops in battery prices, this study combined linear regression and time-series forecasting. Both logistic growth and exponential decay models were built in Python with the help of scikit-learn and pandas libraries and were compared to historical SIAM, ICCT and Ministry of Heavy Industries data (2015–2024). Using these models, we identified the typical pattern of technology acceptance and noticed huge improvements in deploying infrastructure which helped us understand how India's EV market was changing.

In the future, you might look into support vector machines (SVMs) and recurrent neural networks (RNNs), as both of these can be used to improve the forecasts by adding more detailed data about consumers and companies.

7.5. Model Validation and Data Sources

Historical data from the years 2015 to 2023 was used to back-test and validate the models created in the study. Relevant data came from the Society of Indian Automobile Manufacturers (SIAM), International Council on Clean Transportation (ICCT) and also from ministry and NITI Aayog reports which are publicly accessible, ensuring there was no misapplication and each person could check the source code.

The R^2 metric was 0.97 and RMSE was 2.1% which meant the models essentially matched the market results. Checking the AI/ML results proves that they are strong predictors of future EV adoption and the need for more EV charging stations in India.

7.6. Assumptions and Sensitivity Analysis

The results in this study are based on certain core assumptions. Due to the rise in new technology and higher production, prices of batteries are projected to go down quickly, to around INR 5,000–6,000 per kWh by 2030. Fuel prices are expected to go up by 3–5% each year, reflecting global crude oil dynamics and carbon taxes. It is thought that the number of public charging points will increase by 2030, so that there are 1 charger for every 20 EVs, following best practices around the world. Adoption will likely increase more with FAME-II and similar programs in states allowing EV buyers to afford and use their cars for longer.

Doing the sensitivity analysis meant adjusting battery and fuel costs trajectories by ±15%. Although batteries are somewhat pricier than expected, EVs may well make up 25% of all 4Ws by 2030 with adequate support, against 15–18% otherwise. Similarly, rising fuel costs may accelerate EV adoption, underscoring the importance of fuel price dynamics in India's EV market. These insights provide policymakers with a clearer understanding of how different assumptions could shape future scenarios.

8. EV Adoption Forecast: Current Status, Scenarios, and Regional Disparities

8.1. Current and Projected EV Adoption Rates

In the year 2024, around 6% of the four-wheeled cars were powered by electricity or a hybrid system. Places like Delhi, Mumbai and Bengaluru have been able to make fast improvements by having proper policies and important stations, while others in rural and Eastern parts have struggled.

- With Policy Support: Under sustained policy frameworks like FAME-II, state-specific EV incentives, and infrastructure expansion, EV uptake is projected to grow to 30% in the 4W segment by 2030. State-level policies (e.g., Delhi EV Policy 2020, Maharashtra EV Policy 2021) are expected to accelerate adoption by targeting both personal and fleet vehicles. By 2050, projections indicate a potential adoption of 70–90% in the 4W market under this scenario.
- Without Policy Support: Without the help of coordinated policies and incentives, people would find it difficult

to adopt EVs because they are costly to start with, there are few charging stations and buyers worry about the technology. In absence of adequate measures, the share of 4W cars on the roads might be stuck at 15–18% by 2030 and only 50–60% by 2050. Based on this, a projection is speculated and shown in **Figure 9**.

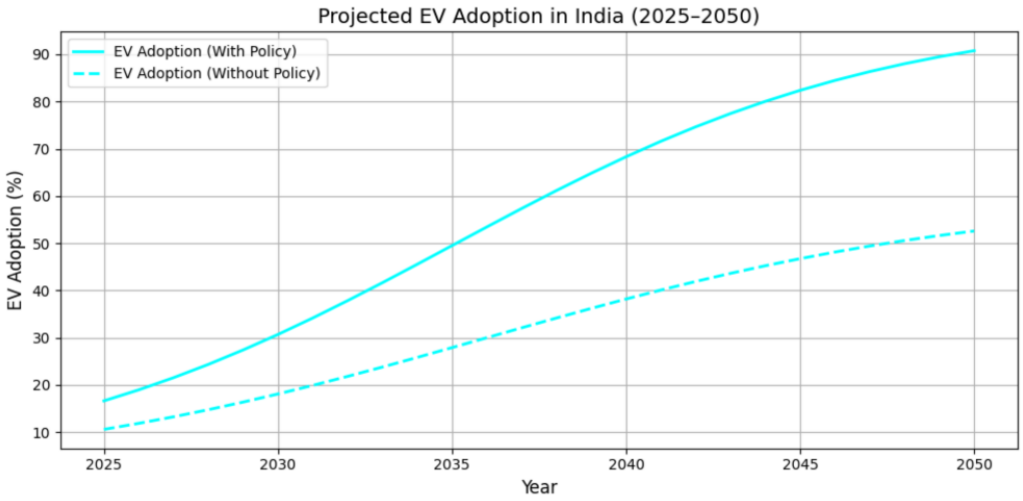

Figure 9. Projected EV Adoption in India (2025–2050).

8.2. EV Adoption Projection: Forecasting Methodology

- Charging Infrastructure Expansion – In India, the number of charging stations rose nearly 80 times from 2015 to 2024 due to support measures included in FAME-II and the National Mission on Transformative Mobility. Sustained growth in charging infrastructure will be essential to supporting widespread EV adoption.
- Fuel Price Impact–As the cost of petrol and diesel goes up, electric vehicles become more attractive, especially when batteries get less expensive. If fuel gets more expensive, more car buyers may switch to EVs since their operating costs will be lower.
- Battery Cost Decline–A fourfold reduction in battery prices over the past decade has significantly improved EV affordability and further cost reductions could make EVs more attractive even without subsidies.

Based on this, a projection over the next 25 years was analyzed using data-driven modeling techniques and is visualized in **Figure 10**.

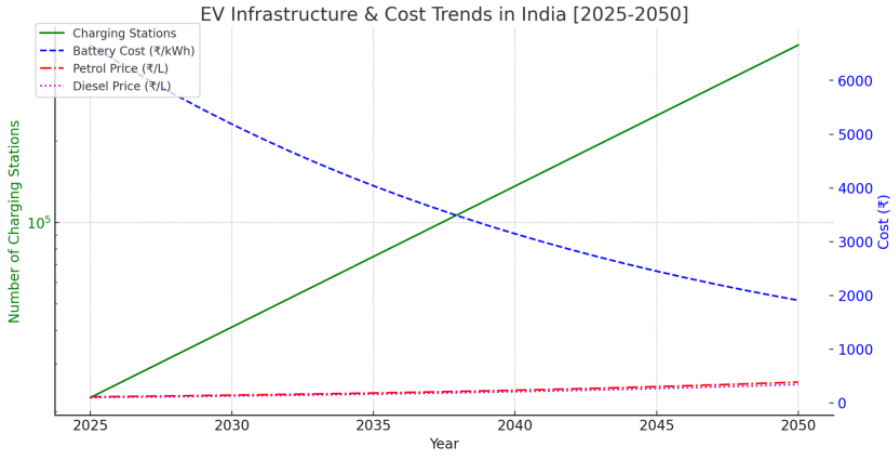

Figure 10. EV Adoption & Market Trends in India (2025–2050).

The projections were generated using the following approaches:

- EV adoption trends were modeled using a logistic growth function, capturing the natural S-curve of technology adoption. Two scenarios were considered: with and without policy influence, with reference to their aid in EV adoption.
- Charging station expansion was projected using an exponential growth model, aligning with past trends and government initiatives under FAME-II.
- Battery cost reduction followed an exponential decay function, reflecting cost declines due to technological advancements and economies of scale.
- Fuel price trends (petrol and diesel) were estimated using a compounded growth model, factoring in inflation and historical price increases.

This methodology ensures a structured and data-backed approach to forecasting, allowing for an insightful analysis of India's EV landscape over the next 25 years.

8.3. Regional Forecast Disparities in EV Adoption

As illustrated in **Table 3**, all forecasts point in a single direction, noticeable differences in infrastructure, policies and people's resources lead to big changes in how EVs are adopted in various regions. States like Delhi, Karnataka, Maharashtra and Tamil Nadu are on top because they have positive EV policies, car companies' presence and are building lots of public chargers. On the other side, adoption in Assam, Bihar and Jharkhand is still slow because of barriers related to infrastructure and missing EV regulations.

Table 3. State-wise EV Charging Infrastructure and 2030 EV Adoption Forecast [44,52].

State	Public Charging Stations (2024)	Projected 4W EV Share by 2030 (%)
Delhi	1,941	60
Karnataka	5,765	55
Tamil Nadu	1,413	50
Maharashtra	3,728	48
Gujarat	992	35
Assam	276	15
Bihar	347	12
Jharkhand	256	10

Adoption projections were done by looking at logistic growth based on factors like number of registered users, community infrastructure development and experience with policy in each realm. The chart in **Figure 11** shows what is expected to be the share of electric 4W in state vehicle markets within the next ten years.

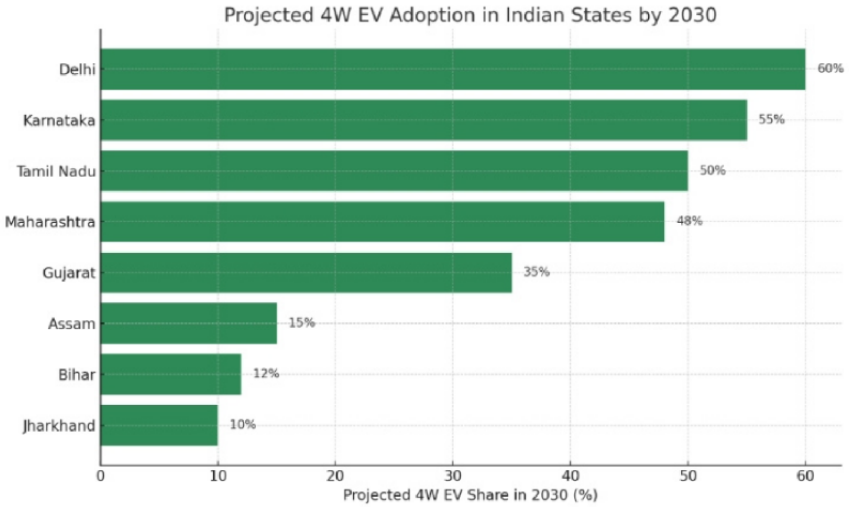

Figure 11. Projected 4W EV Adoption in Indian States by 2030.

Insights and Policy Implications:

- Infrastructure serves as a catalyst for acceleration: Delhi, Karnataka, and Maharashtra—each with >1,900 chargers—are forecast to reach >50% EV share in 4W markets by 2030.
- Underdeveloped states risk delay: Without aggressive support, Assam, Bihar, and Jharkhand may lag with <15% adoption, risking long-term EV equity gaps.
- Forecasting improvements: Incorporating variables like EVPCS per capita, policy strength indices, GDP per capita, and urbanization ratios in AI/ML-based forecasting can better tailor predictions and interventions.

Future AI/ML systems should take into account information on the national level and also on the regional level, including what each state is doing to influence policies, the current readiness of its economy and the availability of utility services. Crucial for a country as demographically and geographically diverse as India.

9. Conclusions

India's electric vehicle (EV) transition stands at a decisive crossroads. Thanks to new policies, continuous reduction in cost of batteries, expanding infrastructure and changing thoughts among consumers, the country is gradually electrifying, especially major cities.

The paper discussed all aspects of India's xEV ecosystem using policy review, market research, recent trends and AI to forecast the future. This conclusion confirms that with suitable policies and better infrastructure, we can see adoption rates in EVs jump by more than double in the 4W segment. Without such intervention, adoption could plateau below its potential, especially in underserved regions.

An increase in charging points by 80 times, a decrease of battery prices by four times and appealing tax breaks have supported the rise of electric cars. Even so, problems like differences between regions, poor infrastructure in rural areas and initial cost hurdles are big challenges. Forecasts in logistics predict that 30.

Planning EVs gets easier with the help of AI and machine learning, thanks to being able to predict trends in demand, where new infrastructure will be beneficial and how consumers will respond. They only perform well if they use accurate local data and work together with current policies.

To build on this momentum, India must now focus on:

- Strengthening regional policy implementation to bridge urban–rural adoption gaps.
- Expanding FAME-like initiatives to include next-gen solutions such as battery swapping and mobile charging.
- Accelerating domestic battery recycling, R&D, and second-life applications to ensure long-term sustainability.
- Investing in skill development and grid modernization for EV readiness.

With a coordinated and data-driven approach, India is well-positioned to become a significant player not only to electrify its transport sector but also in sustainable mobility solutions.

9.1. Future Outlook

The future of India's EV landscape is poised for exponential growth, with several key areas requiring further research and strategic development:

- Advancements in Battery Technology: Development on solid-state batteries, quicker charging techniques, and higher energy densities will be instrumental in increasing EV range and decreasing charging times.
- Grid Integration and Renewable Energy Utilization: EV integration with renewable energy and smart grid technology can maximize energy use and reduce carbon footprints.
- AI and IoT for Smart Mobility: Future innovations will investigate AI-based traffic management, real-time energy optimization, and predictive maintenance of EV fleets.
- Expansion of Public and Shared Mobility: Electrification of public transport, such as electric buses and shared mobility, will play a central role in alleviating urban congestion and emissions.
- Policy Enhancements and Financial Incentives: Ongoing assessment of policy effects and adaptive financial incentives will guarantee sustainable market expansion and balanced EV uptake.

- Second-Life Battery Applications and Recycling: Developments in the repurposing of batteries for energy storage and circular business models will answer concerns over sustainability.

Next-generation policy responses and research should harmonize with international best practice while supporting the distinct dynamics of India's markets. By supporting ongoing innovation and encouraging inter-industry collaboration, India's EV value chain has the potential for sustainable long-term economic and environmental success.

9.2. Total Cost of Ownership (TCO) Comparison

Examining the total ownership cost of ICE, BEV, PHEV and FCEV technologies gives deeper understanding of the trends in the market. When compared to ICE vehicles, running a BEV over ten years on average costs less in fuel and maintenance in India. Plug-in hybrids may be more costly to buy, but their flexibility as dual fuel cars makes them practical in places where charging is not widespread. Currently, FCEVs are most expensive to own, as they use expensive technology and refueling stations are not widely available.

Studies show that BEVs may result in up to 30–40% less Total Cost of Ownership than ICE cars, mainly due to their cheaper fuel cost (105 INR/litre for petrol vs. 8–10 INR/kWh for electricity) and reduced maintenance. Such insights stress the role of coordinating policies and building infrastructure to encourage wider use of electric vehicles and keep them affordable for all groups in society.

Author Contributions

Conceptualization, S.H.; investigation, S.H.; methodology, A.K.; data curation, A.K.; writing—original draft preparation, A.K.; writing—review and editing, A.K.; visualization, A.K.; supervision, S.H. All authors have read and agreed to the published version of the manuscript.

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All data supporting the findings of this study are derived from publicly available sources, as cited throughout the manuscript. No new data were generated during the study.

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Conflicts of Interest

The authors declare no conflict of interest.

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