

# Transforming Transportation in India: Exploring the Challenges and Opportunities of Electric Vehicles

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## Abstract

*Electric vehicles (EVs) are a key solution for cutting greenhouse gas emissions and reducing dependence on fossil fuels. They also help lessen the impact of ozone-depleting substances and support the widespread adoption of renewable energy. Although significant research has focused on EV features, performance, and charging infrastructure, challenges in production and network modeling persist. This paper provides an overview of various EV technologies, including EVs, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs), and evaluates their market penetration rates. It explores various modeling approaches and optimization techniques, addressing key challenges like insufficient charging infrastructure, especially in a developing country like India. The study highlights the emerging concept of vehicle-to-grid (V2G) technology as a potential additional power source when renewable energy is unavailable. The findings emphasize the unique characteristics of EVs in terms of mobility and their potential to reduce CO<sub>2</sub> emissions. Additionally, the paper examines the opportunities and challenges in the Indian EV market, focusing on economic, social, technical, and environmental factors, and provides recommendations for overcoming these barriers to promote EV adoption in India.*

**Keywords:** EV technologies, emissions, EV adoption in India

## INTRODUCTION

Electric vehicles (EVs) are gaining popularity worldwide, including in India [1]. The Indian EV market has seen substantial growth, particularly following the launch of the FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme by the Ministry of Heavy Industries in 2015. In 2018, EV sales in India reached 365,920 units, with projections suggesting a compound annual growth rate (CAGR) of 36% by 2026. Additionally, the EV battery market is expected to expand significantly, with estimates indicating an increase from \$520 million in 2018 to a much larger market in the coming years [2]. As India is one of the largest importers of crude oil, EVs offer a solution for reducing dependence on imported energy resources. Moreover, EVs are considered an effective way to reduce carbon emissions, which are a major cause of air pollution in cities such as Delhi and Mumbai. EVs produce 30–80% less greenhouse gas emissions than traditional vehicles and do not consume energy when stationary, unlike internal combustion engine (ICE) vehicles [3]. However, despite the benefits of EVs, several challenges

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remain. These include issues related to battery life, charging infrastructure, and the range of EVs compared with fossil-fueled vehicles. Additionally, the production of EVs emits more CO<sub>2</sub> than ICE vehicles, although EVs emit zero emissions during operation. As India strives to adopt more EVs, various factors such as government support, technological advancements, and public charging infrastructure will play a critical role in their widespread acceptance [4]. The purpose of this study is to identify the key challenges and opportunities for EV adoption in India, understand the reasons why EVs have not yet gained widespread attention, and highlight government efforts to promote electric and hybrid vehicles [5].

## LITERATURE REVIEW

### Opportunities and Challenges of Electric Vehicles in India

Authors: Menonjyoti Kalita and Golam Imran Hussain, Journal: International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Published by www.ijert.org, NCETER - 2021 Conference Proceedings- Author explained that Growth in the EV sector can stimulate investments and contribute to overall economic development [6].

### Study on Electric Vehicles in India Opportunities and Challenges

Authors: Mohamed, G Tamil Arasan and G, Journal: International Journal of Scientific Research in Environmental Science and Toxicology- The author provided a brief explanation of the study, revealing that while India has significant opportunities for the adoption of electric vehicles, addressing the challenges requires a coordinated effort from various stakeholders. By leveraging technological advancements and government support, India can pave the way for a sustainable and efficient transportation future [2].

### A Review on Barrier and Challenges of Electric Vehicle in India and Vehicle-to-Grid Optimization

Authors: Sonali Goel & Renu Sharma & Akshay Kumar Rathore, Journal: Received 16 August 2020, Revised 4 January 2021, Accepted 17 February 2021, Available online 19 February 2021. The authors stated that vehicle-to-grid technology offers promising opportunities for optimizing energy use and enhancing grid stability, but its successful implementation requires coordinated efforts among stakeholders, including the government, utilities, and consumers. By addressing these barriers and embracing innovative solutions, such as V2G, India can move towards a more sustainable and efficient transportation future [3].

## METHODOLOGY

### Electric Vehicle

In this study, a comprehensive methodology was employed to analyze various aspects of EVs (Figure 1) [7–9]. The study began by classifying EVs into three main categories: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs). Each category was examined to understand its unique characteristics and role in the broader EV market. To explore barriers to EV adoption, three key areas were investigated: market challenges, technical issues, and graphical representations of adoption trends [10]. The market analysis focused on consumer demand, pricing, and the availability of charging infrastructure, whereas the technical investigation explored advancements and limitations in EV technology, including battery efficiency and driving range. Graphical data representation was used to illustrate EV market trends and adoption rates, providing a visual perspective on the identified barriers. In addition, the opportunities and challenges associated with electric vehicles have been explored [11]. This involved identifying the benefits of EVs, such as reduced environmental impact and potential for economic growth, as well as existing challenges, such as infrastructure development and technological limitations [12]. These findings provide a well-rounded understanding of the current EV landscape and its prospects. When studying EV types, it is important to adopt a structured methodology that allows for a comprehensive analysis of various aspects, such as performance, technology, market adoption, and environmental impact. The following are some factors that require consideration.

**Quantitative Data**

- Gather data on vehicle performance (range, charging time, energy consumption).
- Collect statistics on market sales, growth rates, and consumer demographics.
- Obtain information on government incentives and regulations related to each EV type.

**Qualitative Data**

- Conduct interviews or surveys with stakeholders (manufacturers, consumers, and industry experts) to gather insights into preferences, challenges, and perceptions.
- Analyze case studies of successful EV implementations across different types.

**TYPES OF ELECTRIC VEHICLE**

**Hybrid Electric Vehicles**

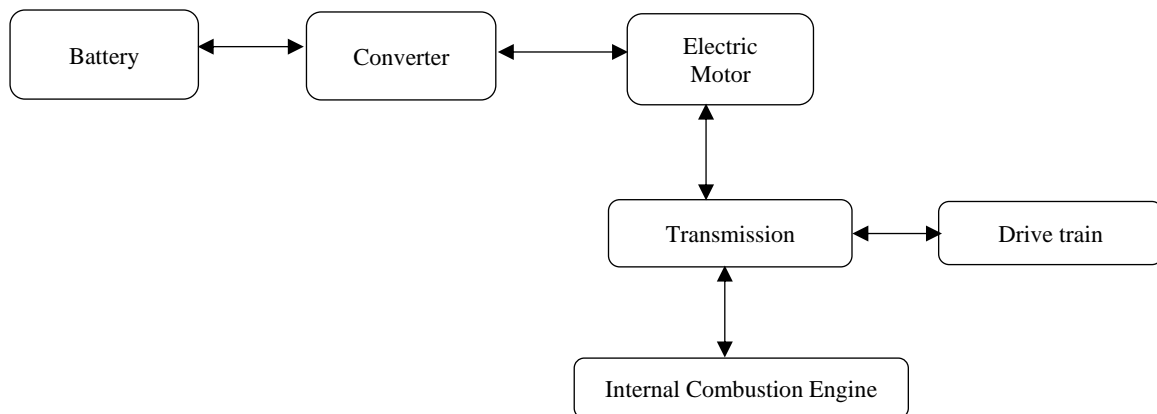
A hybrid electric vehicle combines a gasoline engine with an electric motor to conserve fuel and reduce emissions (Figure 2). The car can switch between using the engine, electric motor, or both, depending on how it is driving. The electric motor receives power from a battery, which recharges when the car slows down or from the engine; therefore, it is not necessary to plug it in. HEVs are suitable for city driving, where the electric motor can handle slow speeds, and the engine kicks in for faster driving. There are different types of hybrids: some use the engine only to generate electricity, others allow the engine and motor to work together, and some can switch between the two. While HEVs save fuel and pollute less, they usually cost more and can only travel a short distance using electric power alone. However, they offer a good option for reducing emissions without the need for charging stations.

**Plug-in Hybrid Electric Vehicles**

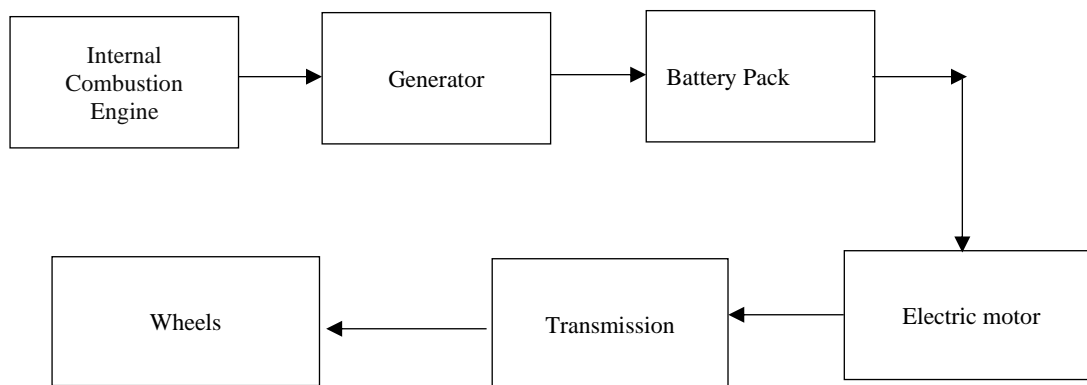
A plug-in hybrid electric vehicle uses both a gasoline engine and an electric motor; however, unlike regular hybrids, it can be charged by plugging into a power outlet (Figure 3). This allows the car to drive longer with electric power. PHEVs can usually travel 20 to 50 km on electricity alone before switching to a gasoline engine, making them good for short trips or city driving. The car can be charged at home or public charging stations, and it also charges the battery while braking.

Vehicle Type	Barriers of electric vehicle	Others
1. Hybrid electric vehicle	1. EV Market	1. Opportunities of electric vehicles
2. Plug in hybrid electric vehicle	2. Technical	2. Challenges of electric vehicles
3. Battery Electric vehicle	3. Graphical representation	

**Figure 1.** Types of electric vehicles.



**Figure 2.** Simple block diagram of hybrid electric vehicles.



**Figure 3.** Block diagram of plug-in hybrid electric vehicles.

PHEVs have different driving modes, such as electric-only or hybrid, depending on what is required. They are more fuel-efficient and produce fewer emissions than regular cars. However, they are expensive and time-consuming. Despite this, PHEVs offer a good mix of electric driving for short trips and gasoline for longer journeys; therefore, you do not have to worry about running out of power.

### Battery Electric Vehicles

Battery electric vehicles (BEVs) are fully powered by electricity stored in batteries, with no gasoline engines, resulting in zero emissions and making them more environmentally friendly. Their key component is a large lithium-ion battery that powers an electric motor. BEVs can be charged at home or public charging stations, and many offer a range of 200–400 km per charge. Additionally, they feature regenerative braking, a system that recovers energy during braking and returns it to the battery to increase efficiency, and helping to save energy. BEVs accelerate quickly because electric motors provide instant power, and they usually cost less to operate because electricity is cheaper than gasoline, and they require less maintenance. However, there are some challenges, such as finding charging stations, longer charging times compared to filling up a gas tank, and concerns about running out of power. Over time, the battery may lose capacity, thereby reducing the driving range. Overall, BEVs are a great step toward cleaner transportation and offer an efficient alternative to traditional gas-powered cars.

### OPPORTUNITIES OF ELECTRIC VEHICLES IN INDIA

1. *Environmental benefits:* EVs generate no tailpipe emissions, helping reduce pollution in cities. This can help combat India's growing air quality concerns, particularly in cities, such as Delhi and Mumbai.
2. *Reduction in oil Imports:* India is one of the largest importers of crude oil. Widespread adoption of EVs could reduce a country's dependency on foreign oil, save billions, and improve energy security.
3. *Government initiatives and subsidies:* The Indian government has introduced several policies to promote EVs, including tax incentives, subsidies, and a Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme.
4. *Technological advancements:* The rapid development of battery technology is reducing the costs of EVs, making them more accessible. Innovations in charging infrastructure and energy storage also support EV ecosystems.
5. *Job creation:* The EV sector offers numerous employment opportunities in the manufacturing, infrastructure development, and service sectors, from battery manufacturing to electric motor production.
6. *Growth of renewable energy:* EVs complement India's push toward renewable energy. They can act as mobile energy storage systems, stabilizing the grid by storing excess solar and wind power.
7. *Foreign investment:* With global automotive companies shifting towards electrification, India can attract foreign investments in EV manufacturing and R&D, which can further strengthen the economy.

## CHALLENGES OF ELECTRIC VEHICLES IN INDIA

1. *High initial cost:* Despite decreasing battery prices, EVs are still generally more expensive than traditional vehicles, discouraging mass adoption. Subsidies help but may not be sufficient for all buyers.
2. *Inadequate charging infrastructure:* A major bottleneck in EV adoption is the lack of a widespread and reliable charging infrastructure. Although metro cities are experiencing some development, rural and remote areas still lack facilities.
3. *Range Anxiety:* Indian consumers are often reluctant to adopt EVs because of concerns about their range, particularly for long-distance trips, coupled with the lack of sufficient charging stations.
4. *Battery technology and recycling:* Batteries used in EVs, typically lithium-ion batteries, are expensive and have a limited lifespan. Additionally, India lacks robust facilities for battery recycling and disposal, which poses an environmental risk.
5. *Limited EV models:* The number of available EV models in India is still relatively limited, particularly in the budget-friendly and commercial segments, compared to the wide range of conventional vehicles.
6. *Electricity Grid Challenges:* The Indian electricity grid is not fully prepared to handle the additional load from mass EV charging, particularly in areas where power outages are common. The shift to EVs can strain the grid without substantial upgrades.
7. *Supply Chain Constraints:* India relies heavily on imports of key EV components, such as lithium, for batteries. This dependence on foreign suppliers, particularly from China, poses a risk to the EV supply chain.
8. *Consumer awareness and acceptance:* There is still a lack of widespread awareness regarding the benefits and functionality of EVs. Many consumers are skeptical of technology and are unsure of its reliability, safety, and cost-effectiveness.
9. *Skilled workforce shortage:* India's automotive workforce is largely skilled in traditional vehicle manufacturing and maintenance. Skilling the workforce to cater to EVs, particularly in areas such as battery manufacturing and software development, remains challenging.

## ELECTRIC VEHICLE MARKET TRANSFORMATION IN INDIA (2010–2024)

### Phase 1: 2010–2015 (Starting Point)

The EV market began during this period (Figure 4). Only a few companies, such as Reva (now Mahindra Electric), sold electric cars, and demand was low due to high prices and lack of awareness. There were very few charging stations, so EVs were mainly used in specific markets rather than by everyday consumers. In 2013, the government launched the National Electric Mobility Mission Plan (NEMMP) 2020 to encourage EV adoption of electric vehicles. However, its initial impact was minimal because of the limited incentives.

### Phase 2: 2016–2020 (Growth Begins)

From 2016 to 2020, the EV market started to grow more quickly, especially with new models such as the Mahindra e2o and Tata Tigor EV. The government launched the FAME scheme in 2015, offering subsidies for electric vehicles and improving the infrastructure. By 2020, EV sales had risen, particularly for electric two-wheelers, with companies such as Bajaj and Ather entering the market. However, infrastructure remains a challenge, with fewer than 1,000 public charging stations available, and high battery costs limiting the adoption of electric cars.

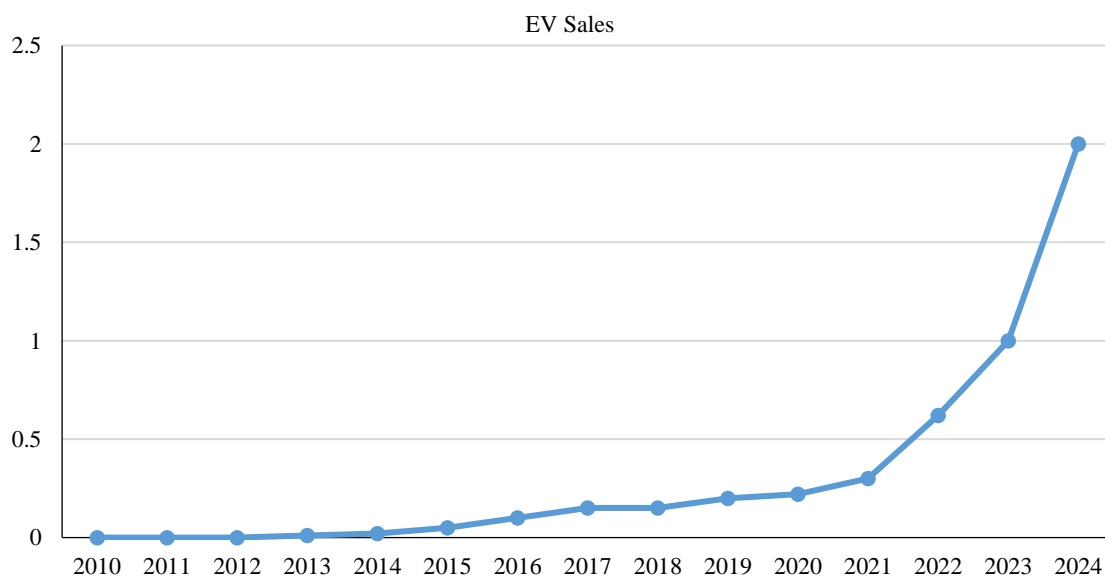
### Phase 3: 2021–2024 (Rapid Expansion)

Between 2021 and 2024, the EV market experienced significant growth. Many automakers have introduced new electric cars, which has led to a surge in sales. In 2021, approximately 330,000 EVs were sold, a 168% increase from the previous year. By 2024, sales are expected to exceed 2 million units, primarily in the two-wheeler segment. The government extended the FAME II scheme to 2024 and implemented various state policies to support the EV sector. Battery prices dropped significantly,

making EVs more affordable, and the number of charging stations increased to more than 1,500. Despite this progress, challenges such as limited charging options in rural areas and slow adoption of electric commercial vehicles remain (Table 1).

**Table 1.** Analysis of electric vehicles (EVs).

Year	EV sales	Charging stations	Key developments	Government policies
2010	<1,000	Negligible	EV market in infancy, Mahindra Reva available	No major policies
2011	Very limited	Negligible	Lack of awareness and infrastructure	No major policies
2012	Very limited	Negligible	Minimal market growth	No major policies
2013	Slight improvement	Negligible	Introduction of the National Electric Mobility Mission Plan (NEMMP)	NEMMP 2020 introduced
2014	Slight improvement	Very limited	Awareness increasing, but slow market growth	NEMMP 2020
2015	~15,000	<100	Launch of FAME I scheme with subsidies for EVs	FAME I launched
2016	Gradual increase	<200	Electric two-wheelers gaining traction	FAME I
2017	Gradual increase	Slow growth	EV demand rising	FAME I
2018	~50,000	~300	Market expansion, focus on two- and three-wheelers	Extension of FAME considered
2019	~130,000	~500	Launch of FAME II with a higher budget	FAME II launched (₹10,000 crore budget)
2020	~150,000	~1,000	Growth despite COVID-19, focus on electric cars (e.g., Tata Nexon EV)	FAME II
2021	~330,000 (168% growth)	~1,300	Surge in two-wheeler sales (Ola, Ather), new state policies introduced	FAME II extended, state-level policies
2022	~600,000	~1,500	Increased adoption of two-wheelers and commercial EVs	Continued FAME II, more state-level policies
2023	>1 million	~1,500	Public-private partnerships in charging infrastructure	FAME II, additional state initiatives
2024	>2 million (estimated)	>2,000 (estimated)	Strong growth expected, focus on affordable EVs and better batteries	FAME II extended, further incentives



**Figure 4.** Representation of this data in graphical form.

## CONCLUSION

Electric vehicles have a significant potential to revolutionize transportation in India by lowering pollution and reducing reliance on fossil fuels. Although government support and increasing awareness are driving the growth of the EV market, challenges such as high costs and a shortage of charging stations remain. Addressing these issues will require investment in advanced technologies and improved infrastructure. Through collaboration and dedicated efforts, India can pave the way for a cleaner and more sustainable future with electric mobility.

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