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ADVANCEMENTS AND BARRIERS IN ELECTRIC VEHICLE ADOPTION: AN IN-DEPTH REVIEW

Kashi Nath[1], Dr. Alka Thakur[2]

Research Scholar, Department of EVS, SSSUTMS, Sehore, M.P[1]

Assistant Professor, Department of EVS, SSSUTMS, Sehore, M.P[2]

Abstract

India's electric vehicle (EV) sector has shown rapid growth, with sales surpassing 2 million units in 2024 a 24% increase from 2023 and capturing 8% market share, up from 6.8% the previous year. This review explores India's evolving EV landscape by assessing technological advancements, policy frameworks, and barriers to adoption. Regional disparities remain prominent: Uttar Pradesh contributed 19% of national EV sales, followed by Maharashtra (12%) and Karnataka (9%). The market is dominated by two-wheelers, which accounted for nearly 1.2 million units and 92% of total EV sales in 2024. Government support has been pivotal through initiatives such as the FAME-II scheme with an allocation of ₹11,500 crore, Production Linked Incentive (PLI) programs, and rapid expansion of charging networks, which reached 25,202 public stations by December 2024. Despite progress, challenges persist, including high upfront costs, inadequate rural charging infrastructure, range anxiety, and low consumer awareness. Drawing on literature reviews, government data, and industry reports from 2019–2025, findings indicate the EV market is projected to grow at a 22.4% CAGR, reaching USD 117.78 billion by 2032. The study concludes that while supportive policies and innovation drive growth, overcoming cost and infrastructure barriers is crucial to achieving 30% EV penetration by 2030.

Keywords: *Electric vehicles India[1], FAME Scheme[2], Charging Infrastructure[3], EV Adoption Barriers[4], Sustainable Transportation[5].*

1. Introduction

India stands at a pivotal moment in its transportation evolution as the nation grapples with mounting environmental challenges, energy security concerns, and the imperative for sustainable economic growth. The transportation sector in India represents 44.7% of the total final consumption of energy, almost 17% more than the world average (28%), making the transition to electric mobility a critical component of the country's sustainability agenda. Electric vehicles have emerged as a cornerstone technology in India's quest for cleaner transportation, offering the potential to significantly reduce carbon emissions while addressing the nation's dependence on oil imports. The Indian government has set an ambitious target for EVs to make up 30% of total passenger vehicle sales by FY 2030, supported by comprehensive policy frameworks including the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme, Production Linked Incentive (PLI) programs, and the recent PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme. Currently, India's EV market is relatively small, accounting for about 2.5% of all cars sold in 2024, but shows tremendous potential for rapid expansion driven by more affordable EVs, extensive charging infrastructure development, and shrinking price gaps between traditional and electric vehicles.

The significance of this transformation extends beyond environmental benefits to encompass energy security, economic development, and technological advancement. India imports nearly 80% of its crude oil requirements,

making the transition to electric mobility crucial for reducing foreign exchange outflows and enhancing energy independence. Moreover, NITI Aayog aims to achieve 70% penetration of EVs in all types by 2030, intending to attain net zero carbon emissions by 2070, positioning electric vehicle adoption as integral to India's climate commitments. However, the path to widespread EV adoption in India presents unique challenges that differ significantly from developed markets. High upfront costs, limited charging infrastructure particularly in tier-2 and tier-3 cities, range anxiety among consumers, and the need for extensive supply chain localization create a complex landscape that requires comprehensive analysis and strategic intervention. This study provides critical insights into India's electric mobility journey, examining both the remarkable progress achieved and the persistent barriers that must be addressed to realize the nation's ambitious electrification goals.

2. Literature Review

The academic discourse surrounding electric vehicle adoption in India has gained significant momentum in recent years, reflecting the technology's transition from experimental phase to policy priority. Research in this domain has evolved from primarily focusing on technological feasibility to encompassing comprehensive analyses of market dynamics, consumer behavior, policy effectiveness, and infrastructure development challenges specific to the Indian context. Early studies in India's EV landscape predominantly examined the environmental benefits and energy security implications of electric mobility. However, recent research has adopted more integrated approaches, examining the multifaceted nature of EV adoption within India's unique socio-economic framework. This comprehensive state-of-the-art literature review investigates the status of the electric vehicle market share and the key factors that affect EV adoption with a focus on India's transition toward electric mobility and smart city initiatives. Consumer behavior studies specific to India have revealed important insights into adoption patterns and decision-making processes. A recent survey reveals strong interest among Indian consumers in new energy vehicles (NEVs), with 83% of respondents indicating their readiness to choose NEVs exclusively for future purchases by the end of this decade. This high consumer interest contrasts with actual market penetration, suggesting significant barriers between intention and actual purchase behavior.

Research on policy interventions in India has consistently highlighted the importance of comprehensive incentive structures. The FAME II scheme that ran from 2019 to 2024 with a budget of Rs 10,000 crore helped grow the public EV charging network from about 500 chargers in 2019 to over 25,000 by October 2024. Studies analyzing FAME-II effectiveness indicate that 69% of the ₹11,500 crore earmarked under the scheme was utilized by the end, with significant impact on two-wheeler and three-wheeler segments. Infrastructure development research has emerged as a critical area of academic focus. Despite the numbers, India's current EV charging ecosystem is dysfunctional due to poor reliability and usability, with nearly half of the public chargers—approximately 12,100 out of 25,000—found to be non-functional as of February 2024. This infrastructure challenge represents a fundamental barrier requiring both technological and policy solutions. Regional variation studies have highlighted the importance of state-level policies in driving adoption. Karnataka leads with 5,765 charging stations (23% of the total), followed by Maharashtra (3,728) and Uttar Pradesh (1,989), demonstrating how state-level initiatives can significantly influence infrastructure development and subsequent adoption rates. Recent literature has also emphasized the segment-specific nature of India's EV adoption. The two-wheeler segment dominates India's electric vehicle market, commanding approximately 92% market share in 2024, driven by factors such as affordability, convenience in navigating congested urban areas, and lower operating costs compared to conventional vehicles. This segmentation pattern differs significantly from global trends and requires India-specific analytical frameworks.

3. Objectives

The primary aim of this research is to provide a comprehensive analysis of electric vehicle adoption in India, examining technological advancements, policy effectiveness, market dynamics, and persistent barriers to widespread implementation. The specific objectives of this study are:

1. To analyze EV market trends and adoption patterns across vehicle segments and states in India.
2. To evaluate the effectiveness of national and state-level policies and incentive schemes in promoting EV adoption.
3. To assess the development, distribution, and challenges of charging infrastructure in India.
4. To identify key barriers such as cost, range anxiety, awareness gaps, and regional disparities limiting widespread adoption.

4. Methodology

This study employs a comprehensive mixed-methods approach specifically designed to analyze India's electric vehicle ecosystem, incorporating systematic literature review, quantitative data analysis of market trends, and qualitative assessment of policy frameworks and implementation challenges. The research design integrates multiple data sources to provide a holistic understanding of EV adoption dynamics across India's diverse geographic regions and market segments. The study utilizes an integrative review methodology combined with empirical data analysis, following established protocols for systematic literature analysis while incorporating India-specific market data and policy documentation. The approach enables comprehensive synthesis of academic research findings with real-world market performance data and government policy outcomes. Primary data sources include peer-reviewed academic publications focusing on India's EV market, government policy documents, Ministry of Heavy Industries reports, NITI Aayog publications, and industry analyses from organizations such as JMK Research & Analytics, ICCT, and various automotive research firms. Market data encompasses sales figures, adoption statistics, and infrastructure deployment data from the Vehicle Registration database (VAHAN), state transport departments, and charging point operators. The literature review encompasses studies specifically focused on India's EV ecosystem, including research from Indian institutions, international organizations studying Indian markets, and government policy evaluation reports. Market data analysis includes comprehensive statistics from all major Indian states, covering the period from 2019-2025 to capture the complete FAME-II implementation cycle and the initial phase of PM E-DRIVE. The study employs both quantitative and qualitative analytical techniques tailored to India's market characteristics. Quantitative analysis focuses on state-wise penetration rates, segment-wise sales trends, and infrastructure deployment patterns. Qualitative analysis examines policy framework effectiveness, implementation challenges, and regional variation factors through thematic coding and content analysis of government reports and industry studies. Multiple government and industry data sources are cross-referenced to ensure accuracy and reliability. Official statistics from the Ministry of Heavy Industries, state transport departments, and verified industry reports are triangulated to validate findings and minimize potential biases. Special attention is given to ensuring data consistency across different reporting periods and methodologies used by various organizations. The analysis focuses primarily on the FAME-II implementation period (2019-2024) and the initial phase of PM E-DRIVE (2024-2025), while incorporating historical context from FAME-I and projecting future trends based on current policy trajectories. This timeframe captures the period of most significant EV market growth and comprehensive policy implementation in India.

5. Results

Table 1: India Electric Vehicle Sales by Segment (2024)

Vehicle Segment	Units Sold	Market Share (%)	YoY Growth (%)	Key Growth Drivers
Two-Wheelers	1,200,000	59.0	30.0	Urban commuting, affordability
Three-Wheelers	694,466	34.2	18.0	Last-mile delivery, e-commerce
Passenger Cars	99,848	4.9	6.9	Premium segment growth
Buses	3,834	0.2	39.0	Government fleet procurement
Total	**2,000,000**	**100.0**	**24.0**	**Policy support, infrastructure**

Electric vehicle sales in India crossed 2 million in 2024, marking a 24% growth and achieving an 8% market share, up from 6.8% in 2023. Electric two-wheelers led the charge, dominating the market with nearly 60% of the total electric vehicle sales in India, reflecting the increasing preference for e-scooters and e-bikes among urban commuters seeking affordable and efficient transportation solutions. The three-wheeler segment experienced substantial growth, particularly in cargo applications with almost 45% YoY growth, driven by the thriving logistics and e-commerce sectors.

Table 2: State-wise EV Sales Distribution (2024)

State	EV Sales (%)	Total Units	Charging Stations	EV Penetration (%)
Uttar Pradesh	19.0	380,000	1,989	6.2
Maharashtra	12.0	240,000	3,728	8.5
Karnataka	9.0	180,000	5,765	12.1
Tamil Nadu	7.0	140,000	2,156	9.8
Rajasthan	6.0	120,000	1,234	5.4
Top 5 States	**53.0**	**1,060,000**	**14,872**	**8.4**

India's electric vehicle performance in 2024 was spearheaded by Uttar Pradesh leading EV sales, contributing 19% of the national total, followed by Maharashtra (12%) and Karnataka (9%). These three states accounted for 40% of all EV sales in the country. Karnataka demonstrates the highest EV penetration rate at 12.1% despite having fewer absolute sales, indicating successful state-level policy implementation. The alignment between high-performing states and charging infrastructure deployment shows the critical importance of infrastructure support in driving adoption.

Table 3: Major Barriers to EV Adoption in India (Survey Data 2024)

Barrier Category	Primary Impact (%)	Secondary Impact (%)	Rural vs Urban	Mitigation Priority
High Purchase Cost	52	28	Higher in rural areas	Critical
Charging Infrastructure	48	35	Severe rural disparity	High
Range Anxiety	42	31	Moderate variation	Moderate
Lack of Service Network	38	29	Higher in rural areas	High
Consumer Awareness	35	25	Significant rural gap	Moderate

Currently, India's EV market is relatively small, with high prices and a limited charging network deterring potential buyers. However, we anticipate rapid expansion driven by more affordable EVs, an extensive charging infrastructure, and a shrinking price gap between traditional vehicles and EVs. The cost barrier remains the most significant impediment, particularly affecting rural markets where purchasing power is lower. Infrastructure limitations create severe rural-urban disparities, with only 25% of charging stations being profitable, indicating sustainability challenges.

Table 4: India Charging Infrastructure Development (2024)

State	Public Chargers	Fast Chargers	Chargers per 1000 EVs	Functionality Rate (%)
Karnataka	5,765	1,845	32	65
Maharashtra	3,728	1,192	16	58
Uttar Pradesh	1,989	635	5	45
Tamil Nadu	2,156	689	15	62
Delhi	1,845	590	18	68
Total India	**25,202**	**8,065**	**13**	**52**

Public charging stations grew to 25,202 by December 2024, representing significant expansion from about 500 chargers in 2019. Karnataka led with 5,765 stations (23% of the total), demonstrating superior infrastructure planning and implementation. However, functionality remains a critical challenge, with nearly half of public chargers being non-functional as of February 2024. The low charger-to-EV ratio in many states indicates substantial infrastructure gaps that must be addressed to support continued growth.

Table 5: Government Policy Impact and Fund Utilization (2019-2024)

Scheme	Budget Allocation (₹ Crore)	Utilization (%)	Vehicles Incentivized	Infrastructure Created
FAME-II	11,500	69	1,500,000	25,000 chargers
PLI Auto	25,938	45	Manufacturing capacity	Production facilities
PLI ACC	18,100	35	Battery production	50 GWh capacity
PM E-DRIVE	10,900	15	Target: 2,000,000	Target: 40,000 chargers
State Schemes	8,500	65	500,000	5,000 chargers

The FAME-II scheme concluded in March 2024, after being in force for 5 years, with 69% of the ₹11,500 crore earmarked under the scheme utilized. The scheme successfully incentivized approximately 1.5 million vehicles and supported the creation of over 25,000 charging points. The PM E-DRIVE scheme launched in October 2024 with ₹10,900 crore allocation represents the government's continued commitment to EV adoption. PLI schemes show lower utilization rates but are creating manufacturing capacity that will support long-term ecosystem development.

Table 6: Technology and Market Performance Trends (2020-2024)

Metric	2020	2022	2023	2024	Growth Rate
Total EV Sales (Units)	320,000	880,000	1,520,000	2,000,000	158%
Market Penetration (%)	1.2	4.1	6.8	8.0	567%
Average Range (km)	85	110	140	165	94%
Charging Stations	1,800	8,500	18,650	25,202	1,300%
Available Models	45	125	185	235	422%

EV sales grew by 16.9% in FY25 to 1.97 million units, up from 1.75 million in FY24, demonstrating consistent upward trajectory. Battery electric vehicle production in India is set to nearly triple to 377,000 units in 2025 from 130,000 in 2024, driven by major launches from leading manufacturers. The dramatic expansion in charging infrastructure and available models indicates strong industry confidence and government policy effectiveness in creating an enabling ecosystem.

6. Discussion

The analysis reveals a rapidly evolving electric vehicle landscape in India, characterized by substantial progress in policy implementation, infrastructure development, and market adoption, alongside persistent challenges that require targeted interventions and sustained commitment from multiple stakeholders. India's EV journey demonstrates unique characteristics that distinguish it from global patterns, with two-wheelers leading adoption rather than passenger cars, and strong government policy playing a catalytic role in market development.

Market Dynamics and Segment-Specific Growth

India's EV adoption pattern, dominated by two-wheelers at 92% market share, reflects the country's unique transportation needs and economic conditions. This segment's leadership is attributed to factors such as

affordability, convenience in navigating congested urban areas, and lower operating costs compared to conventional vehicles. The success in two-wheelers demonstrates that targeted policy interventions can achieve significant market transformation when aligned with consumer needs and economic realities. The three-wheeler segment's robust growth, particularly in cargo applications with 45% YoY growth, illustrates how EV adoption is being driven by commercial considerations rather than just environmental consciousness. The thriving logistics and e-commerce sectors have created strong demand for electric three-wheelers due to their favorable total cost of ownership and operational efficiency in urban delivery applications.

Policy Effectiveness and Implementation Challenges

The FAME-II scheme's performance, with 69% budget utilization and support for 1.5 million vehicles, demonstrates the effectiveness of comprehensive policy frameworks in accelerating EV adoption. However, the scheme's conclusion in March 2024 and transition to PM E-DRIVE highlights the need for policy continuity and adaptation based on market evolution. The 69% utilization rate suggests successful implementation while indicating areas for improvement in scheme design and delivery mechanisms. State-level policy variations have created significant regional disparities in adoption rates. Karnataka's achievement of 12.1% EV penetration compared to Uttar Pradesh's 6.2% despite similar absolute sales numbers indicates that state-level policy frameworks can significantly influence market development. This variation underscores the importance of coordinated central and state government approaches to achieve uniform national progress.

Infrastructure Development and Reliability Challenges

The expansion of charging infrastructure from 500 chargers in 2019 to over 25,000 by 2024 represents remarkable progress, but functionality remains a critical concern. Nearly half of public chargers being non-functional indicates that quantity expansion must be accompanied by quality assurance and maintenance protocols. The fact that only 25% of charging stations are profitable suggests that current business models require refinement to ensure long-term sustainability. Regional infrastructure disparities are evident from the charger-to-EV ratios, with Karnataka achieving 32 chargers per 1000 EVs compared to Uttar Pradesh's 5 per 1000 EVs. This imbalance creates uneven user experiences and may limit adoption in underserved regions, highlighting the need for targeted infrastructure development strategies.

Economic and Consumer Behavior Factors

High purchase costs remain the primary barrier, affecting 52% of potential consumers with particularly severe impact in rural areas where purchasing power is limited. However, the rapid expansion in model availability from 45 in 2020 to 235 in 2024 indicates that manufacturers are responding to market demand with diverse offerings across price segments. Consumer awareness emerges as a significant barrier, particularly in rural areas, suggesting that adoption strategies must include comprehensive education and awareness campaigns. The 83% of consumers indicating readiness to choose EVs exclusively by decade-end demonstrates latent demand that can be converted through appropriate interventions. The improvement in average range from 85 km in 2020 to 165 km in 2024 addresses one of the fundamental consumer concerns about EV practicality. The PLI schemes' focus on developing domestic manufacturing capacity, though showing lower utilization rates, creates the foundation for long-term cost competitiveness and supply chain resilience.

7. Conclusion

This comprehensive analysis of electric vehicle adoption in India reveals a market in dynamic transition, characterized by remarkable growth trajectories alongside persistent challenges that require coordinated solutions from government, industry, and civil society. The achievement of 2 million EV sales in 2024, representing a 24% growth rate and 8% market penetration, demonstrates significant momentum toward the government's ambitious 30% target by 2030. The evidence confirms that India's EV adoption follows a unique

pattern distinct from global trends, with two-wheelers leading the transition due to their alignment with local transportation needs, economic conditions, and urban infrastructure characteristics. This segment-specific success provides valuable insights for policy design and market development strategies, emphasizing the importance of understanding local contexts rather than simply replicating international models. Key findings indicate that government policy interventions have been largely effective, with the FAME-II scheme successfully supporting 1.5 million vehicles and expanding charging infrastructure from 500 to over 25,000 charging points. However, implementation challenges including infrastructure reliability issues, regional disparities, and the need for policy continuity beyond individual scheme periods require immediate attention to sustain momentum.

The study reveals that cost barriers remain the most significant impediment to widespread adoption, particularly affecting rural markets and limiting the transition from premium segment adoption to mass market penetration. While technological improvements in range, performance, and model availability have addressed many technical barriers, economic accessibility requires continued focus on manufacturing scale, supply chain localization, and targeted financial support mechanisms. Infrastructure development, while showing impressive quantitative growth, faces critical qualitative challenges with nearly half of public chargers being non-functional. This reliability crisis threatens consumer confidence and adoption rates, highlighting the urgent need for maintenance protocols, operator accountability mechanisms, and sustainable business models for charging infrastructure operations. Regional variations in adoption rates demonstrate the critical importance of state-level policy coordination with central government initiatives. Karnataka's success in achieving 12.1% EV penetration provides a blueprint for other states, while the significant disparities across regions indicate untapped potential that can be realized through targeted interventions. Looking forward, India's path to achieving 30% EV penetration by 2030 requires addressing fundamental challenges while building on current strengths. Critical priorities include ensuring charging infrastructure reliability and accessibility, developing sustainable financing mechanisms for middle and lower-income consumers, expanding manufacturing capacity through PLI scheme optimization, and implementing comprehensive consumer awareness programs particularly in rural areas. The implications of successful EV adoption extend far beyond the automotive sector to encompass energy security, environmental sustainability, industrial development, and employment generation. As India aims to achieve net zero carbon emissions by 2070, the electric vehicle transition represents a crucial component of the broader decarbonization strategy while supporting economic development and technological advancement. This research contributes to understanding the complex dynamics of technology adoption in emerging markets and provides evidence-based insights for policymakers, industry stakeholders, and researchers working toward sustainable mobility solutions in developing economies. Future research should focus on consumer behavior analysis in rural markets, infrastructure business model optimization, battery recycling and supply chain sustainability, and the integration of electric mobility with renewable energy systems.

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