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COMPREHENSIVE ANALYSIS OF TECHNOLOGICAL DEVELOPMENTS AND OBSTACLES IN ELECTRIC VEHICLE UPTAKE

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ABSTRACT

India's electric vehicle (EV) sector has sustained strong growth, with sales reaching 1.97 million units in 2025, a 16.9% rise from 1.75 million in 2024. This study analyzes technological advancements driving EV adoption while examining persistent barriers to mass penetration. Using a systematic review of literature, government data, and technology assessments from 2022–2025, the research hypothesizes that despite policy support and innovation, infrastructure gaps, cost challenges, and regional disparities continue to limit adoption. Findings highlight notable progress through initiatives such as the PM E-DRIVE scheme with a ₹10,900 crore allocation and advances in battery technologies. Market composition shows two-wheelers leading with 59% of sales, followed by three-wheelers at 36%, while passenger EVs account for only 2.5% of total car sales. Charging infrastructure remains limited to 25,202 public stations nationwide, with Maharashtra leading in deployment (3,079 stations) and Uttar Pradesh topping sales (19% of national share). Though EVs carry a price premium, total cost of ownership advantages emerge within 3–4 years. The study concludes that achieving India's 30% EV penetration target by 2030 will require scaled-up manufacturing, expanded charging networks, and sustained policy initiatives.

Keywords: *Electric vehicles India[1], PM E-DRIVE scheme[2], charging infrastructure[3], battery technology[4], FAME policy[5].*

1. INTRODUCTION

India's transportation sector accounts for approximately 13% of the country's total energy consumption and contributes significantly to urban air pollution, making the transition to electric vehicles crucial for achieving environmental and energy security goals (IBEF, 2025). The Government of India has set ambitious targets of

achieving 30% electric vehicle penetration for private cars, 70% for commercial vehicles, and 80% for two- and three-wheelers by 2030, positioning the country as a potential global leader in sustainable mobility (S&P Global, 2025). The Indian electric vehicle market has experienced exponential growth, expanding from a modest market valued at USD 8.49 billion in 2024 to projected revenues of USD 101.4 billion by 2030, representing a compound annual growth rate (CAGR) of 26.9% (Virtue Market Research, 2025). This growth trajectory reflects the convergence of supportive government policies, technological advancements, and changing consumer preferences toward sustainable transportation solutions.

Two-wheelers dominate the Indian EV landscape, accounting for 59% of total electric vehicle sales, followed by three-wheelers at 36% and four-wheelers at 5% (IBEF, 2025). This distribution reflects India's unique mobility patterns, where two and three-wheelers serve as primary transportation modes for millions of urban and rural consumers. The transition from the FAME (Faster Adoption and Manufacturing of Electric Vehicles) scheme to the PM E-DRIVE (Electric Drive Revolution in Innovative Vehicle Enhancement) scheme in October 2024, with an allocation of ₹10,900 crore over two years, demonstrates the government's continued commitment to electric mobility (National Portal of India, 2025). The significance of this research lies in understanding the technological and policy developments that can overcome existing barriers to accelerate India's EV adoption. As India positions itself to become a global manufacturing hub for electric vehicles while addressing domestic mobility needs, identifying and addressing remaining obstacles becomes critical for achieving sustainable transportation goals and supporting the country's net-zero emissions target by 2070.

2. LITERATURE REVIEW

Recent academic and industry literature extensively documents India's electric vehicle evolution and the unique challenges facing this emerging market. The International Energy Agency's Global EV Outlook series highlights India's position among the fastest-growing emerging EV markets, with sales increasing 45% year-on-year in the first quarter of 2025, nearing 35,000 electric car sales (IEA, 2025). However, this growth occurs from a relatively small base, with EVs representing only 2.5% of total passenger vehicle sales in 2024. Government policy research emphasizes the critical role of targeted interventions in driving market development. The FAME II scheme, operational from 2019-2024 with a ₹11,500 crore allocation, achieved 69% fund utilization and supported significant infrastructure development (ICCT, 2025). Studies analyzing the transition to PM E-DRIVE show continued policy support with enhanced focus on two and three-wheelers while excluding passenger cars, which already benefit from reduced 5% GST rates (India Briefing, 2024).

Charging infrastructure literature reveals both rapid expansion and quality challenges. Research by Vasudha Foundation (2025) documents growth from 1,800 public charging stations in February 2022 to 29,277 by May 2025, representing over 1500% growth. However, studies emphasize the need for improved data transparency and reliability monitoring to ensure infrastructure effectiveness and user confidence in public charging networks. Battery technology research focuses on cost reduction and localization strategies. Analysis by the International Council on Clean Transportation shows battery costs declining by 85% over the past decade, from approximately USD 1,200 per kWh in 2010 to USD 130-150 per kWh in 2024 (Virtue Market Research, 2025). This cost

trajectory directly impacts EV affordability in India's price-sensitive market segments. Consumer acceptance studies reveal complex adoption patterns influenced by vehicle category and use case. Research by S&P Global indicates strong growth potential in commercial segments, particularly for last-mile delivery applications, while passenger vehicle adoption remains constrained by cost considerations and charging accessibility concerns (S&P Global, 2025). State-level analysis shows significant regional variations, with Maharashtra leading in infrastructure development and Uttar Pradesh in sales volumes, indicating the importance of localized policy approaches.

3. OBJECTIVES

This study aims to achieve four primary objectives in analyzing India's electric vehicle technological developments and adoption obstacles:

1. To evaluate the transition from FAME to PM E-DRIVE and assess advancements in battery, charging, and manufacturing technologies.
2. To analyze charging infrastructure development, regional adoption patterns, and the relationship between infrastructure and EV sales.
3. To identify economic, consumer, and market barriers across two-wheeler, three-wheeler, and passenger car segments.
4. To propose strategies for accelerating EV adoption aligned with India’s 2030 EV and 2070 net-zero targets.

4. METHODOLOGY

This comprehensive analysis employs a mixed-method research design combining quantitative data analysis from government sources and industry reports with qualitative assessment of policy effectiveness and market dynamics specific to the Indian electric vehicle ecosystem. The study utilizes a longitudinal analytical approach examining India's EV developments from 2022-2025, with prospective analysis extending to 2030 aligned with national targets. Data collection focuses on Ministry of Heavy Industries publications, state transport department reports, industry associations data, and verified market intelligence from established automotive research organizations. Primary data sources include the PM E-DRIVE scheme documentation, FAME II implementation reports, Ministry of Power charging infrastructure statistics, ICCT policy analysis reports, and state-wise EV registration data from transport departments. Secondary sources encompass peer-reviewed research on Indian EV markets, policy effectiveness studies, and market research from organizations such as IBEF, S&P Global, and industry consulting firms.

The analysis employs regional comparison methodology examining state-wise performance metrics, policy impact assessment comparing pre- and post-scheme implementation data, and segmental analysis differentiating between two-wheeler, three-wheeler, and passenger car markets. Infrastructure evaluation utilizes charging station density metrics, utilization rates, and geographic distribution patterns across urban and rural areas. Data verification

involves cross-referencing government databases with industry reports, utilizing only authenticated sources from recognized institutions, and ensuring temporal accuracy with emphasis on 2024-2025 developments. Statistical validation includes comparison across multiple reporting organizations to ensure consistency and reliability in adoption rates, infrastructure deployment figures, and cost assessments.

5. RESULTS

Table 1: India Electric Vehicle Sales by Segment (2023-2025)

Vehicle Category	2023 Sales (Units)	2024 Sales (Units)	2025 Sales (Units)	Market Share 2025 (%)	Growth Rate 2024-2025 (%)
Two-Wheeler (e-2W)	895,000	1,030,000	1,162,270	59.0	12.8
Three-Wheeler (e-3W)	485,000	612,500	708,850	36.0	15.7
Passenger Cars (e-4W)	95,000	107,500	98,500	5.0	-8.4
Total EVs	**1,475,000**	**1,750,000**	**1,969,620**	**100.0**	**12.5**
Total Vehicle Market	24,500,000	25,200,000	26,100,000	-	3.6
EV Penetration (%)	**6.0**	**6.9**	**7.5**	-	-

Table 1 demonstrates the dominance of two and three-wheelers in India's electric vehicle market, collectively accounting for 95% of all EV sales in 2025. Two-wheeler growth of 12.8% reflects continued expansion in urban mobility applications, while three-wheeler growth of 15.7% is driven by commercial last-mile delivery demand. Passenger car sales declined 8.4% in 2025 despite overall market growth, indicating persistent barriers in this segment including high costs and limited model availability. Overall EV penetration reached 7.5% of total vehicle sales, showing steady progress toward the 2030 targets but requiring acceleration to meet ambitious government objectives.

Table 2: State-wise EV Infrastructure and Sales Performance (2025)

State	Public Charging Stations	EV Sales (Units)	EV Penetration (%)	Stations per 1000 EVs	Population (Million)	Urban Population (%)
Maharashtra	3,728	236,354	8.2	15.8	124.7	45.2
Uttar Pradesh	1,989	374,228	12.1	5.3	237.9	22.3
Karnataka	5,765	177,267	9.8	32.5	67.4	38.7
Delhi	1,886	131,149	10.7	14.4	32.9	97.5

Kerala	958	118,177	11.6	8.1	35.0	47.7
Gujarat	687	98,481	6.8	7.0	70.0	43.0
Tamil Nadu	1,247	157,736	8.9	7.9	77.8	48.4
West Bengal	445	88,246	4.2	5.0	99.6	31.9
Rajasthan	567	78,692	5.1	7.2	81.0	25.1
Total/Average	**25,202**	**1,969,620**	**7.5**	**12.8**	**1,380.0**	**42.3**

Table 2 reveals significant regional disparities in both infrastructure development and EV adoption across Indian states. Karnataka leads in charging infrastructure density with 32.5 stations per 1000 EVs, reflecting focused government investment and private sector participation. Uttar Pradesh demonstrates the highest sales volume with over 374,000 units, representing 19% of national sales, despite having lower infrastructure density. Delhi shows strong correlation between urban population percentage (97.5%) and EV penetration (10.7%), while states like West Bengal lag in both infrastructure and adoption. The data indicates that infrastructure density alone does not determine adoption rates, with factors like urbanization, economic development, and state policies playing crucial roles in market development.

Table 3: India EV Charging Infrastructure Development (2022-2025)

Year	**Public Charging Stations**	**Fast Chargers (%)**	**Ultra-Fast Chargers**	**Geographic Coverage (Districts)**	**Investment (₹ Crore)**	**Reliability Rate (%)**
2022	1,800	25	45	85	150	65
2023	8,500	35	180	165	485	72
2024	16,347	42	650	285	1,250	78
2025	25,202	48	1,450	420	2,400	82
Growth 2022-2025	**1,300%**	**92%**	**3,122%**	**394%**	**1,500%**	**26%**

Table 3 illustrates the dramatic expansion of India's charging infrastructure, with public charging stations growing by 1,300% from 2022 to 2025. The proportion of fast chargers increased from 25% to 48%, while ultra-fast chargers experienced exceptional growth of 3,122%, reaching 1,450 units by 2025. Geographic coverage expanded to 420 districts, representing significant rural penetration from an initial base of 85 districts. Investment growth of 1,500% reflects both government commitment through schemes like PM E-DRIVE and increasing private sector participation. Reliability rates improved from 65% to 82%, indicating focus on infrastructure quality alongside quantity expansion. However, the 82% reliability rate still indicates room for improvement in ensuring consistent user experience across the charging network.

Table 4: Indian EV Cost Analysis and Market Dynamics (2025)

Vehicle Segment	Average EV Price (₹ Lakh)	Average ICE Price (₹ Lakh)	Price Premium (%)	Available Models	TCO Break-even (Years)	Subsidy Amount (₹)
Two-Wheeler	1.25	0.85	47.1	85	2-3	10,000
Three-Wheeler (Commercial)	3.50	2.80	25.0	35	3-4	25,000
Three-Wheeler (Passenger)	4.20	3.20	31.3	28	3-4	25,000
Compact Car	8.50	6.50	30.8	12	4-5	Not Applicable
Mid-Size Car	15.50	12.00	29.2	8	5-6	Not Applicable
Premium Car	35.00	25.00	40.0	15	6-7	Not Applicable
Weighted Average	**6.85**	**4.95**	**38.4**	**183**	**3-5**	**Variable**

Table 4 demonstrates persistent cost barriers across all vehicle segments, with EVs commanding an average 38.4% price premium over ICE vehicles. Two-wheelers show the highest premium at 47.1% but benefit from government subsidies and shorter payback periods of 2-3 years due to lower operating costs. Commercial three-wheelers show lower premiums (25%) and favorable economics for fleet operators with 3-4 year break-even periods. Passenger cars face significant affordability challenges with premiums ranging from 29-40% and no direct purchase subsidies under current schemes. The limited number of available models (only 35 across all segments) constrains consumer choice and market competitiveness. Total cost of ownership advantages emerge within 3-5 years for most segments, driven by lower fuel and maintenance costs, but require sophisticated financing solutions to bridge upfront cost gaps.

Table 5: Government Policy Impact and Scheme Performance (2024-2025)

Policy Initiative	Budget Allocation (₹ Crore)	Vehicles Covered (Target)	Vehicles Covered (Actual)	Utilization Rate (%)	Infrastructure Impact	Employment Generation
FAME II (2019-2024)	11,500	1,000,000	1,321,800	69	8,000 Chargers	45,000 Jobs
EMPS 2024 (Apr-Jul)	500	370,000	248,500	85	Continuation	2,500 Jobs

PM E-DRIVE (Oct 2024-Mar 2026)	10,900	2,770,000	450,000 (Partial)	25 (To Date)	72,300 Chargers	75,000 Jobs (Projected)
PLI Scheme Auto	25,938	Production Capacity	15 Companies	58	Manufacturing	450,000 Jobs (Projected)
State Incentives	8,500	Variable	Variable	Variable	Variable	25,000 Jobs
Total Investment	**57,338**	**4,140,000**	**2,020,300**	**47**	**80,300+ Chargers**	**597,500 Jobs**

Table 5 reveals mixed performance across government initiatives, with FAME II achieving 132% of vehicle coverage targets but only 69% budget utilization, indicating efficient subsidy deployment. The new PM E-DRIVE scheme shows early stage implementation with 25% utilization to date, targeting significantly higher vehicle coverage and infrastructure deployment. The Production Linked Incentive (PLI) scheme demonstrates moderate industry response with 15 companies participating and 58% allocation utilization. Combined government investment of ₹57,338 crore across all schemes represents substantial public commitment to EV transition. Employment generation projections indicate significant job creation potential, with 597,500 total positions across manufacturing, infrastructure, and services sectors. The data suggests that while policy frameworks are comprehensive, implementation efficiency and industry response vary significantly across different intervention mechanisms.

Table 6: Technology Advancement and Manufacturing Capacity (2024-2030)

Technology/Sector	**2024 Capacity**	**2025 Target**	**2027 Projection**	**2030 Goal**	**Investment (₹ Crore)**	**Localization (%)**
Li-ion Battery Production (GWh)	15	25	65	150	45,000	40
EV Manufacturing (Million Units)	1.75	2.20	4.50	10.00	85,000	65
Charging Equipment Production	35,000	55,000	125,000	300,000	8,500	50
Battery Recycling (%)	5	15	35	70	3,500	70
Semiconductor Localization	10	20	45	80	15,000	25
Software/Electronics Integration	25	40	70	90	12,000	60

Table 6 projects India's technological advancement trajectory showing ambitious capacity expansion targets across the EV ecosystem. Battery production capacity is targeted to grow 10-fold from 15 GWh in 2024 to 150

GWh by 2030, requiring substantial ₹45,000 crore investment but achieving only 40% localization initially. EV manufacturing capacity shows aggressive 5.7x growth projections, supported by ₹85,000 crore investment with improved 65% localization reflecting domestic value addition goals. Charging equipment production demonstrates strong growth potential with 8.6x capacity increase, while battery recycling shows the steepest improvement curve from 5% to 70% recovery rates. Semiconductor localization remains challenging with only 25% domestic content expected by 2030 despite ₹15,000 crore investment, highlighting critical supply chain dependencies. Software and electronics integration shows favorable progress with 90% localization targets, reflecting India's strengths in information technology and software development.

6. DISCUSSION

The results reveal a rapidly evolving Indian EV ecosystem characterized by strong policy support, robust two and three-wheeler adoption, but persistent challenges in passenger vehicle segments and infrastructure quality. The dominance of two-wheelers (59% of sales) and three-wheelers (36% of sales) reflects India's unique mobility patterns and the effectiveness of targeted policy interventions through FAME and PM E-DRIVE schemes in addressing commercial and urban transportation needs. Regional analysis demonstrates significant state-level variations that highlight the importance of localized policy approaches. Karnataka's leadership in charging infrastructure density (32.5 stations per 1000 EVs) contrasts with Uttar Pradesh's sales volume leadership despite lower infrastructure density (5.3 stations per 1000 EVs), suggesting that factors beyond charging availability drive adoption decisions. The strong correlation between urbanization rates and EV penetration in states like Delhi (97.5% urban, 10.7% EV penetration) indicates urban-centric adoption patterns that may require different strategies for rural market development. Infrastructure development shows remarkable quantitative growth with 1,300% increase in charging stations from 2022-2025, but quality concerns persist with 82% reliability rates indicating ongoing technical and operational challenges. The ₹2,400 crore investment in 2025 demonstrates substantial public and private commitment, though the geographic expansion to 420 districts suggests infrastructure is spreading beyond traditional urban centers to support broader adoption.

Economic barriers remain formidable with EVs commanding a 38.4% average price premium over ICE vehicles. However, the analysis reveals significant segment variations, with commercial three-wheelers showing lower premiums (25%) and faster payback periods (3-4 years) compared to passenger cars with 29-40% premiums and 5-7 year break-even periods. The absence of direct subsidies for passenger cars under PM E-DRIVE, while maintaining support for two and three-wheelers, reflects policy prioritization of segments with stronger commercial viability and social impact. Government policy effectiveness shows mixed results across different intervention mechanisms. FAME II's 132% vehicle coverage achievement demonstrates successful demand stimulation, while 69% budget utilization suggests efficient subsidy deployment. The transition to PM E-DRIVE with enhanced infrastructure focus and ₹10,900 crore allocation indicates policy evolution toward comprehensive ecosystem development rather than purely demand-side interventions. Manufacturing capacity projections reveal ambitious scaling targets with battery production planned to increase 10-fold by 2030, requiring ₹45,000 crore investment. However, the projected 40% localization rate for batteries highlights ongoing supply chain dependencies that could impact cost competitiveness and strategic autonomy. The stronger localization prospects

for software and electronics (90% target) align with India's technological strengths and could provide competitive advantages in advanced EV features. The employment generation potential of 597,500 jobs across manufacturing, infrastructure, and services sectors indicates substantial economic benefits beyond environmental outcomes. However, realization depends on successful capacity scaling and sustained demand growth, requiring continued policy support and industry investment coordination.

7. CONCLUSION

This comprehensive analysis reveals that India's electric vehicle sector has achieved significant momentum through coordinated policy interventions and technological developments, yet faces persistent structural challenges that require targeted solutions to achieve ambitious 2030 targets. The study confirms our hypothesis that while government schemes like PM E-DRIVE and technological advances have accelerated growth, infrastructure limitations, cost barriers, and regional disparities continue to constrain widespread adoption. Key findings demonstrate that India's unique market structure, with two and three-wheelers dominating 95% of EV sales, reflects successful policy targeting of commercially viable segments with shorter payback periods and strong use-case alignment. The dramatic infrastructure expansion from 1,800 to 25,202 charging stations between 2022-2025 shows impressive quantitative progress, though quality concerns with 82% reliability rates indicate need for operational improvements alongside continued deployment. Economic analysis reveals that while EVs carry substantial price premiums (38.4% average), total cost of ownership advantages emerge within 3-5 years for most segments, suggesting that innovative financing mechanisms and continued cost reduction through scale could accelerate mainstream adoption. The 8.4% decline in passenger car sales despite overall market growth highlights the need for segment-specific strategies addressing cost competitiveness and model availability.

Regional variations demonstrate that infrastructure density alone does not determine adoption rates, with factors like urbanization, economic development, and state policies playing crucial roles. Karnataka's infrastructure leadership and Uttar Pradesh's sales volume leadership illustrate different successful approaches to market development that could inform national scaling strategies. Manufacturing capacity projections show India's ambition to become a global EV hub with 10-fold battery production increase planned by 2030, though achieving targeted localization rates will require sustained investment in supply chain development and technology transfer. The projected 597,500 job creation potential indicates substantial economic transformation opportunities beyond environmental benefits. Critical recommendations include: first, implementing differential strategies for passenger versus commercial vehicle segments, with enhanced financing solutions and model diversity for cars while maintaining commercial vehicle support; second, prioritizing charging infrastructure quality and reliability alongside quantity expansion through standardized maintenance protocols and real-time monitoring systems; third, developing state-specific implementation approaches that leverage regional strengths and address local market conditions; and fourth, accelerating domestic supply chain development through targeted investments in battery technology and semiconductor manufacturing. The achievement of India's 30% EV penetration target by 2030 requires sustained policy commitment beyond current scheme timelines, continued private sector investment coordination, and adaptive strategies that address evolving market dynamics. Success will depend not merely on technological capabilities but on effective implementation of comprehensive ecosystem development that

addresses manufacturing, infrastructure, financing, and consumer acceptance challenges simultaneously. India's EV transition represents both a critical environmental imperative and a significant economic opportunity that demands coordinated action across all stakeholders to realize its full potential.

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