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Energizing the Future: Assessing India's Electric Vehicle Ecosystem, Policies, and Market Dynamics

[1]Ajit A. Katkar, [2]Pratibha D. Patil, [3]Kiarn R. Jadhav, [4]Asawari Bhalerao, [5]Priya Pawar, [6]Kasturi B. Nikumbh,
[1]Associate Professor, Sanjeevan Group of Institutions, Panhala, Kolhapur, Maharashtra, India
[245]Assistant Professor, International Institute of Information Technology, Pune, India
[3]Assistant Professor, Bharati Vidyapeeth's College of Engineeing Lavale, Pune, India
[6]Assistant Professor, PES's Modern College of Engineering, Pune, India, Email- ajit.katkar@gmail.com

Abstract
This study explores the evolution of India's electric vehicle (EV) ecosystem, highlighting both accomplishments and persistent challenges. It delves into significant government initiatives such as the FAME II and Production Linked Incentive (PLI) programs, which promote market growth and enhance infrastructure [1]. The research assesses the present condition of India's charging infrastructure, local manufacturing capabilities, and the supply chains for essential raw materials needed for EV production [2]. It also examines market trends, including the rising popularity of luxury electric vehicles and two-wheelers, to understand consumer adoption patterns [9]. The study identifies hurdles such as high battery costs, inadequate charging facilities, and dependence on imported components [5]. Furthermore, it reviews significant investments and partnerships that are shaping the industry landscape [10]. The necessity of establishing domestic battery production and recycling systems for supply chain resilience is emphasized [4]. The paper identifies consistent policy frameworks, technological progress, and active private sector participation as crucial elements for success. Recommendations are provided to enhance the ecosystem's resilience in achieving the target of 30% electric vehicle sales by 2030. This research aims to guide policymakers, manufacturers, and investors committed to advancing sustainable transportation in India.
Keywords: Electric Vehicles (EVs), Smart Grid Integration, EV Charging Infrastructure, Renewable Energy, Policy Frameworks, EV Market Trends, Battery Technology, Vehicle-to-Grid (V2G), India EV Policy

1. INTRODUCTION

India's transition towards electric mobility is motivated by environmental concerns and economic opportunities. The escalating urban air pollution, increasing greenhouse gas emissions, and significant reliance on imported fossil fuels necessitate a shift to electric vehicles (EVs) for sustainable development [4]. Additionally, enhancing manufacturing self-sufficiency is part of the country's 'Make in India' and 'Atmanirbhar Bharat' initiatives, with EV production being a vital aspect [7]. The Indian government has set an ambitious target for electric vehicles to account for 30% of all new vehicle sales by 2030 to achieve these interconnected goals [2]. Recent market analyses show a substantial rise in luxury EV sales, which increased by 66% year-on-year, indicating a favorable shift in consumer preferences in the premium segment [9]. Concurrently, government initiatives like the FAME II scheme, the PLI scheme, and various state-level incentives have played a crucial role in shaping the EV landscape [1], [6]. However, the path to widespread EV adoption is not without its challenges. Issues such as limited charging infrastructure, high vehicle costs, and a fragile domestic battery supply chain pose significant barriers to large-scale implementation [3], [5].
Moreover, India's dependence on imported lithium and other critical materials raises questions about the long-term sustainability of its EV sector [4]. To alleviate market concerns, especially in the two-wheeler and commercial vehicle segments, targeted awareness initiatives and financial incentives will be essential [10]. Engaging the private sector, attracting foreign direct investment, and fostering technology partnerships are critical steps to bridge existing capability gaps. This paper conducts a comprehensive analysis of these factors and offers actionable strategies to ensure the success of India's EV goals within the established timeline.

2. Government Policy & Incentives

India's rapid advancement towards electric mobility is greatly influenced by supportive policies at both the national and state levels. These frameworks are designed to eliminate market entry barriers, stimulate manufacturing, and accelerate the adoption of electric vehicles (EVs) across diverse segments, including two-wheelers, passenger cars, buses, and commercial fleets [2].

1. National Initiatives

FAME India Scheme (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles)

Launched in 2019, FAME II has a budget of ₹10,000 crore (approximately US$1.2 billion) [1].

Salient Features:

- Financial support for 1 million electric two-wheelers, 500,000 electric three-wheelers, 55,000 electric cars, and 7,000 electric buses.
- Assistance for establishing public charging infrastructure, which helps mitigate initial costs and range anxiety.
- Coverage also includes fleet vehicles such as electric buses, rickshaws, and taxis used in public transport.

Outcome: By 2023, the scheme has facilitated the subsidization of over 700,000 EVs [2].

b) PLI Scheme (Production Linked Incentive) for Automobiles and ACC Battery Manufacturing

With a total budget of ₹26,000 crore, this scheme allocates:

- ₹18,000 crore for the Advanced Chemistry Cell (ACC) Battery Storage Program, aimed at increasing local battery production.
- ₹8,000 crore for manufacturing incentives for original equipment manufacturers (OEMs), applicable to EVs, hydrogen fuel cell vehicles, and essential components like motors and power electronics.
- Goal: To develop a robust domestic EV supply chain and reduce dependence on imported batteries [1].

2. Incentives for Zero Emission Vehicles (ZEV)

NITI Aayog, India's premier policy-making body, has announced that financial incentives and subsidies will focus exclusively on Battery Electric Vehicles (BEVs), excluding traditional hybrids and plug-in hybrids (PHEVs) [2].

- Objective: Align with India's zero tailpipe emissions goals and international climate commitments outlined in the Paris Agreement [7].
- Effect: This creates a stable policy environment for manufacturers to invest in fully electric platforms rather than transitional technologies [5].

3. State-Level EV Initiatives

a) Uttar Pradesh

Provides purchase subsidies for two-, three-, and four-wheeler EVs. Mandates the establishment of:

- Charging stations in commercial buildings, parking areas, and fuel outlets [6].
- Exemptions from road tax and registration fees for EV purchasers.

b) Haryana

Plans to create dedicated EV parks—industrial zones designed for EV component and vehicle manufacturing. Incentives include:

- Capital subsidies for equipment and machinery [6].
- Concessional land rates for EV manufacturers and related industries.
- Assistance for establishing R&D centers and training facilities for the EV sector [2].

c) Other Progressive States:

States such as Maharashtra, Tamil Nadu, Gujarat, and Delhi:

- Provide additional incentives for buyers, tax breaks, and plans for infrastructure development [3]. Tamil Nadu's strategy aims to position the state as an export hub for EVs with special economic zones (SEZs) for EV and battery manufacturing [4].

Challenge	Description
Policy Fragmentation	Varied incentives across states create confusion for manufacturers.
Short-term Focus on Subsidies	Heavy reliance on subsidies may hinder market-driven cost reductions.
Lack of Recycling Guidelines	Absence of a comprehensive policy for battery end-of-life recycling.
Unclear ICE Phase-out Timelines	Lack of specific deadlines for phasing out Internal Combustion Engine (ICE) vehicles.

Opportunities for Policy Advancement

- Standardizing EV purchase incentives and charging rates at the national level [2].
- Initiating scrappage and battery recycling programs to establish a closed-loop battery system [4].
- Creating green bonds and financing products to attract private investment in EV infrastructure [3].
- Promoting hydrogen fuel cell vehicles for heavy-duty uses alongside BEVs [5].

India's proactive policy framework—anchored by initiatives like FAME II and PLI—has established a robust foundation for the growth of electric mobility. However, enhanced coordination between central and state authorities, clarity on long-term objectives, and a focus on sustainability (such as battery recycling) are critical for ensuring a seamless and economically viable transition to clean transportation [7].

3. Charging & Grid Infrastructure

Robust charging infrastructure is vital for mass EV adoption:

- Charging station growth: India had approximately 12,000 public stations by FY 2024 but needs between 600,000 to 1.4 million by 2030 to achieve a 4:1 EV-to-station ratio [8].
- Fast charging network: Tata Motors plans to increase fast chargers to 400,000 in two years, including 120 kW "Mega Chargers" [3].
- Operational challenges: Ongoing issues with downtime—BPCL's chargers show non-functional rates of 7% to 30%; a Reddit note mentions, "there aren't enough fast chargers and many … can't be used" [11].
- Grid impact: Existing grids may not support rapid expansion. Smart grid upgrades, renewable integration, and bidirectional charging are essential [12].

Without vehicle-to-grid readiness and reliable uptime, EV adoption will be slow due to persistent range anxiety.

4. Market Adoption & Trends

- Passenger & luxury EV sales: EVs already account for approximately 4.1% of new passenger car sales as of May 2025; luxury EV sales rose by 66%, totaling 2,027 vehicles in the first five months [10][9].
- Two- and three-wheelers: E-rickshaw and low-power scooter segments face significant safety issues, such as fire hazards and regulatory loopholes [9].
- Consumer behavior: Studies indicate that Indian buyers are willing to pay about USD 10–40 more for shorter charging times and increased range, emphasizing the importance of reliable fast chargers [13].

5. Supply-Chain & OEM Dynamics

Category	Details
1. Challenges with Critical Materials	Concern: Reliance on imported raw materials, especially rare earth elements (neodymium, lithium).
	Recent Development: China has restricted exports of key rare earth materials.
	Effect: Maruti Suzuki reduced e-Vitara EV production forecast from 26,500 to 8,200 units.

	Outcome: Risk of falling short on production and sales targets without alternative sources.
2. Investments by OEMs	Tata Motors:
	- Investment: ₹350 billion (approx. US$4.1 billion) over the next five years.
	- Focus Areas: EV platform development, battery technology, clean-tech solutions.
	- Goal: Launch 15 new EV models by 2030.
	Other Manufacturers: Mahindra and Hyundai increasing capacity and local assembly to reduce imports.
3. Battery Manufacturing Initiative	Government Strategy: Production Linked Incentive (PLI) under Advanced Chemistry Cell (ACC) program to boost local battery production.
	Aim: Reduce dependence on imports.
	Key Components:
	- Financial incentives for giga-factories.
	- Promotion of lithium-ion and sodium-ion technologies.
	- Localizing supply chains for battery components.
4. Battery Swapping and Commercial Models	SUN Mobility:
	- Collaborations: With Amazon, Zomato, Indian Oil Corporation (IOCL).
	- Offering: Battery swapping technology for two-wheelers, three-wheelers, and small commercial vehicles.
	- Benefits: Reduces downtime and upfront costs; accelerates EV adoption.
	- Expansion Plans: Swapping stations in over 20 cities in India.
Challenges in Supply Chain & OEM Dynamics	- High import dependency on battery-grade lithium, cobalt, and nickel.
	- Exposure to geopolitical risks (e.g., China's export controls).
	- Need for domestic exploration of rare earth minerals in Odisha and Rajasthan.
	- Slow ramp-up of domestic gigafactories.
	- Lack of standardization in battery swapping systems.
Future Opportunities	- Exploration of lithium reserves in Jammu & Kashmir.
	- Establishment of multi-brand battery swapping stations.
	- Growing FDI interest in India's EV battery sector.
	- Support for solid-state and sodium-ion battery research.

Critical material constraints: Global rare-earth export curbs—especially by China—have forced Maruti to cut its e-Vitara production from 26,500 to ~8,200 units.
OEM investments: Tata Motors has committed ₹350 billion (US$4.1 b) over five years to EV and clean-tech expansion, planning 15 models by 2030.
Battery manufacturing push: The PLI's ACC scheme aims to build domestic value chains for advanced cell production [1][2].
Swapping and commercial models: SUN Mobility, collaborating with Amazon, Zomato, IOCL, etc., is rolling out battery-swap systems across vehicle segments.

India's EV manufacturing ambitions hinge on securing battery raw materials and reducing supply-chain dependency.

6. Key Challenges

Infrastructure deficits: Charger availability and uptime remain inconsistent; grid capacity is stretched.

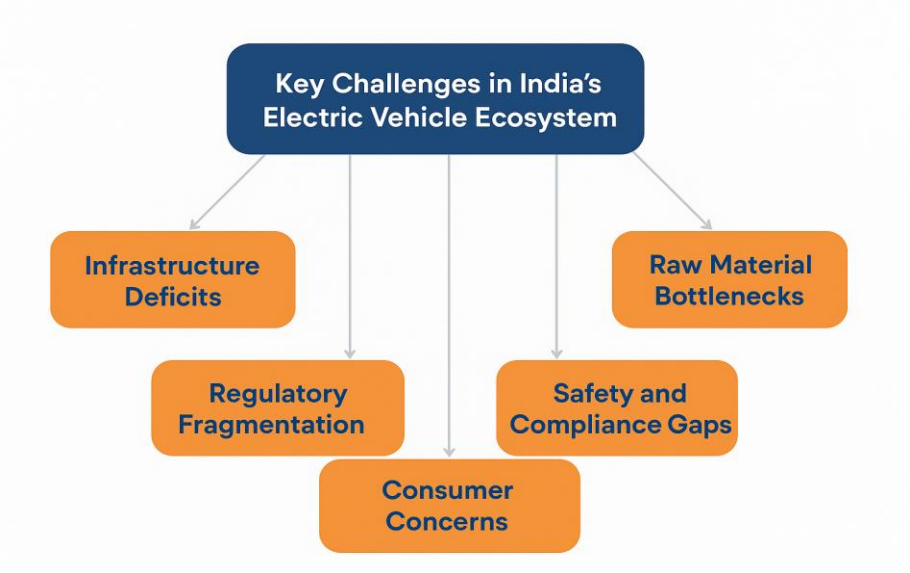
Regulatory fragmentation: Inconsistent SOPs and lack of standardization for charges and battery swapping create operational uncertainty (ecogears.in).

Safety and compliance gaps: Widespread use of unsafe lead-acid batteries in e-rickshaws and unregistered scooters raises hazards (drishtiias.com).

Raw material bottlenecks: Dependence on imports and China's restrictions threaten production targets .

Consumer concerns: Range anxiety, high initial costs, and limited financing options make adoption challenging (1charging.com).

Environmental paradox: Coal-dependent grid reduces EVs' emission benefits; EV battery recycling infrastructure remains underdeveloped (drishtiias.com).



7. Opportunities & Strategic Recommendations

- Unified regulatory standards: Implement "One Nation, One Charger" protocol and battery-swapping SOPs [8].
- Infrastructure resilience: Prioritize uptime, reliability, and grid modernization; integrate renewables with charging stations [4].
- Promote fast-charging: Expand DC fast chargers and Tata's Mega Charger initiative; improve uptime to reduce range anxiety [3].
- Localize battery production: Leverage PLI schemes to foster domestic Advanced Chemistry Cell (ACC) facilities and reduce import dependency [7].
- Strengthen e-2W safety: Enforce quality control and registration; upgrade to safe battery technology in e-rickshaws and scooters [2].
- Financing and business innovation: Encourage favorable EV loan terms; support battery leasing/swapping models like SUN Mobility [5].
- Recycling frameworks: Scale battery repurposing and recycling, incorporating EVs into the e-waste strategy [2].

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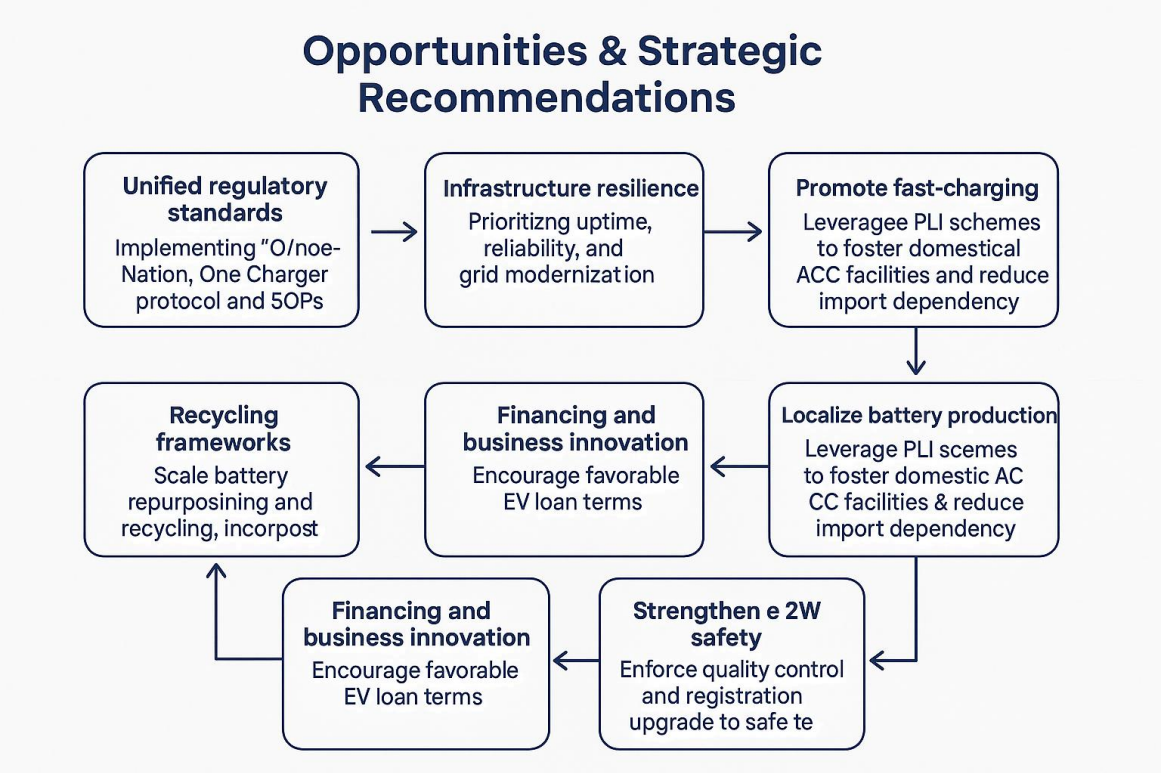

The successful integration of electric vehicles (EVs) into India's energy infrastructure demands the establishment of a robust, smart, and sustainable grid framework. The occurrence of widespread blackouts, both within India and globally, underscores the pressing need to bolster grid reliability to accommodate the increasing demand from EVs [16]. Implementing solar energy solutions through grid-connected rooftop systems, such as the 8kW model analyzed in recent research, can decentralize charging facilities and ease the burden on centralized power grids [17]. Emerging computational intelligence techniques are becoming essential for optimizing power flow, detecting faults, and forecasting loads, offering substantial benefits in managing the complexities introduced by EVs [18]. Furthermore, initiatives aimed at generating renewable energy align with India's objectives for decarbonization and promoting clean EV charging [19]. The use of Artificial Intelligence (AI) for identifying faults enhances grid resilience by facilitating quicker and more precise responses to disturbances in the system [20]. As the market penetration of EVs rises, maintaining voltage stability is crucial; recent surveys have highlighted the importance of advanced optimization methods for analyzing stability in modern power systems [21]. Additionally, effective reactive power management strategies play a vital role in sustaining voltage levels during periods of high EV demand [22]. These advancements collectively highlight the interdependent nature of developing the EV ecosystem and upgrading intelligent power systems, both of which are essential for fulfilling India's vision of a sustainable energy and mobility future. The incorporation of sophisticated computational approaches into India's EV landscape offers significant opportunities for optimizing power distribution and ensuring grid resilience. Recent studies have emphasized the impact of artificial intelligence (AI), machine learning (ML), and deep learning (DL) in enhancing the strategic placement of distributed generation (DG) sources, which can bolster localized charging infrastructure and mitigate transmission losses [23]. The deployment of smart grid technologies is pivotal for improving the operational efficiency and reliability of power systems, particularly in the context of increasing EV adoption and the resultant surge in electricity demand [24].Innovations in AI-driven frameworks for DG placement not only improve voltage stability and balance grid loads but also resonate with India's broader aspirations for sustainable electrification and decentralized energy management [25]. Collectively, these findings underline the critical importance of integrating intelligent energy management solutions to support the burgeoning electric mobility landscape in India.

8. CONCLUSION

India's electric vehicle (EV) ecosystem is currently at a crucial turning point, influenced by forward-thinking policies, targeted incentives, and growing consumer interest. The government's commitment to promoting Zero Emission Vehicles (ZEVs), backed by initiatives such as FAME II [1] and the Production Linked Incentive (PLI) program [2], has laid the groundwork for swift EV adoption, with additional support from state-level initiatives that enhance local engagement [6]. Nevertheless, challenges such as insufficient infrastructure [3], supply chain vulnerabilities [5], and consumer uncertainties [13] pose significant barriers to progress. To overcome these issues, it is essential to implement standardized charging solutions [8], modernize the power grid [12], foster domestic battery manufacturing [7], and develop innovative business strategies [2]. By advancing strategic policies and encouraging private sector participation [4], India can realize its ambition of becoming a global leader in the EV market. Strengthening these critical areas will be vital for the country to achieve its 2030 EV sales targets and create a sustainable, self-sufficient mobility future.

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