Impact of Electric Vehicles on India's Energy Demand and Emission Reduction: A Review

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Abstract—Electric Vehicles (EVs) are increasingly viewed as a critical solution to India's challenges of rising energy demand, oil import dependency, and greenhouse gas (GHG) emissions from the transport sector. This review presents a comprehensive analysis of EV adoption in India and its implications for national electricity demand and emission reduction. The study examines EV penetration trends, impacts on the power grid, lifecycle emissions, and the role of renewable energy integration. Results from recent studies indicate that EVs significantly reduce tailpipe emissions and petroleum consumption; however, their overall climate benefits strongly depend on India's electricity generation mix and charging strategies. The paper concludes that coordinated policy measures linking EV deployment with grid decarbonization and smart charging infrastructure are essential to maximize environmental and energy security benefits.

Index-Terms: Electric Vehicles (EVs); Energy Demand; Greenhouse Gas (GHG) Emissions; Lifecycle Assessment; Grid Decarbonization; Renewable Energy Integration; Smart Charging; India Transport Sector.

I. INTRODUCTION

India's transport sector contributes significantly to national energy demand and urban air pollution. With increasing vehicle ownership and fossil fuel consumption, greenhouse gas emissions continue to rise. EV adoption is framed as a strategy to improve energy security and reduce emissions while supporting India's climate ambitions. Recent policy initiatives seek to increase EV penetration to over 30% of new vehicle sales by 2030 and to expand charging infrastructure nationwide. NITI Aayog's focus on zero-emission vehicles underscores this shift [1]. Electric Vehicles (EVs) are proposed as a strategic solution to reduce dependence on imported fuels, improve air quality, and reduce emissions. Government policies like FAME (Faster Adoption and Manufacturing of Electric

Vehicles), PLI (Production Linked Incentives), and the PM E-DRIVE scheme aim to accelerate EV adoption. In India, the sector accounts for nearly 20–25% of total final energy consumption and approximately 13% of energy-related CO_2 emissions, with road transport being the dominant contributor [2]. Rapid urbanization, population growth, and rising income levels have led to a sharp increase in vehicle ownership, resulting in escalating demand for petroleum fuels and severe air quality degradation in urban centers such as Delhi, Mumbai, and Bengaluru [3]. India's electricity sector is still dominated by coal-based generation, accounting for approximately 70% of total electricity production, which raises concerns about indirect emissions associated with EV charging [4]. Sen et al. [5] conducted a comprehensive scenario-based analysis of large-scale vehicle electrification in India and found that even under coal-heavy grid conditions, EVs offer net reductions in $PM_{2.5}$ and NO_x emissions, yielding substantial air-quality and health benefits. Furthermore, when combined with moderate grid decarbonization pathways, EV adoption could reduce CO_2 emissions from road transport by 15–40% by 2040, depending on vehicle segment and charging patterns. Similar conclusions were reported by Sarkar et al. [6], who highlighted that near-term grid decarbonization significantly amplifies the climate benefits of transport electrification. From an energy demand perspective, several studies argue that concerns regarding excessive electricity demand from EVs are often overstated. According to the International Council on Clean Transportation (ICCT), even aggressive EV adoption scenarios would require less than 1% additional electricity generation by 2030 and approximately 5–10% by 2040, which is manageable within India's planned capacity expansion [5], [7]. India's policy landscape strongly reflects these research findings. National initiatives such as FAME-II, Production Linked Incentive (PLI) schemes for batteries, and the PM E-DRIVE program aim to accelerate EV adoption while strengthening domestic manufacturing and charging infrastructure [8]. At the same time, India has committed to achieving 500 GW of non-fossil electricity capacity by 2030, which is expected to substantially reduce grid emission intensity and improve the lifecycle emissions performance of EVs [9].

II. EV ADOPTION TRENDS IN INDIA

Electric vehicle adoption in India has experienced rapid growth over the past decade, evolving from negligible presence to a significant and accelerating share in the country's transport sector. This transformation is driven by supportive government policies, declining EV costs, expanding charging infrastructure, and rising environmental awareness among consumers. However, the pattern and rate of adoption vary widely across vehicle segments (two-wheelers, three-wheelers, passenger cars, and buses) and geographic regions, with two- and three-wheelers dominating the adoption landscape [10], [11], [12].

Historical Growth and Market Expansion: India's EV market witnessed a remarkable upward trend in annual electric vehicle sales over recent years. EV sales surged from under 100,000 units in 2017–18 to nearly 1.67 million units by 2023–24, representing an approximate 61% compound annual growth rate (CAGR) over this period. This dramatic increase reflects rising consumer

interest coupled with expanding product offerings across segments. In terms of registered EV units, cumulative EV registrations in India soared from about 1.3 million units in 2018 to over 15 million by 2023, driven largely by strong demand for two-wheelers and three-wheelers [10].

Segment-Wise Adoption Patterns:
Two-Wheelers (E2W): Electric two-wheelers form the largest share of EV sales in India, driven by affordability, utility for daily commuting, and favourable policies like FAME II incentives. In FY25 data, e-2W penetration shows strong performance, with near 58% of total EV sales comprised of two-wheelers, reflecting their role as the backbone of personal EV adoption. [10]

Three-Wheelers (E3W): India is recognized as the world's largest electric three-wheeler market, with over 50% of new three-wheelers sold in 2024 being electric. This segment's strong performance is attributed to commercial use, lower operating costs, and government fleet electrification policies. [14]

Passenger Cars (E4W): Compared to two- and three-wheelers, the electric car segment is yet emerging but showing notable growth. Passenger EV sales crossed 100,000 units, with approximately 18% year-on-year growth in 2024, supported by expanding model availability and improving charging infrastructure.

Buses and Commercial Vehicles: Electric buses are being deployed under national schemes (e.g., PM-eBus and PM E-Drive) to electrify public transport, with tens of thousands of units sanctioned and rolled out in states like Andhra Pradesh. [13]

Table 1 EV Adoption by Vehicle Segment in India

Vehicle Category	Key Adoption Features	Approximate Share of Total EV Sales	Growth Trend
Two-wheelers (E2W)	Affordable, daily commute, high volume	~57–58% (FY24)	Strong growth (rapid adoption)
Three-wheelers (E3W)	Commercial use, high electrification	>50% new 3W sales (2024)	Leading adoption
Passenger Cars (E4W)	Premium EVs & fleet uptake	~35,000 units (FY25)	Growing but moderate
Buses	Public transport electrification	Thousands sanctioned under national schemes [13]	Expanding

A line chart showing the rise in EV sales from ~95,000 units in 2017–18 to ~1.97 million in 2023–24, with segment breakdowns (E2W, E3W, E4W).

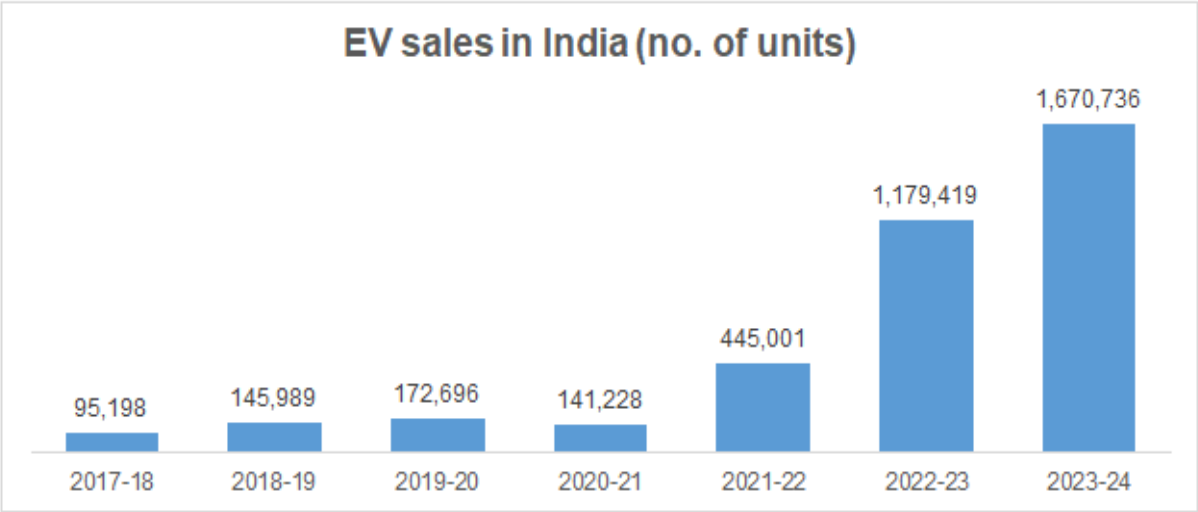

Figure 1 Annual EV Sales Growth in India (2017–2024) [10]

III. EVS AND INDIA'S ENERGY DEMAND

The transition from internal combustion engines (ICE) to electric vehicles (EVs) fundamentally shifts energy consumption patterns in the transport sector—moving demand from imported fossil fuels to domestically generated electricity. This shift carries profound implications for India's national energy demand profile, power grid operation, and long-term energy planning. EV adoption increases electricity demand as vehicles require charging energy supplied by the electric grid. This additional load must be incorporated into India's energy planning and generation strategies. According to projections under India's EV30@30 campaign (30% EV share by 2030), EV charging demand could add 15–30 terawatt-hours (TWh) of electricity consumption annually by 2030, alongside increases in peak load requirements. Such demand growth presents both opportunities and challenges for the power sector [15]. A recent industry report notes that EV energy consumption in India could account for approximately 6–8.7% of national electricity generation by 2035, driven by growth in EV stock and charging infrastructure [16].

Projected Electricity Demand from EV Charging: Table 2 presents projections of electricity demand resulting from anticipated EV adoption under multiple scenarios. Projections integrate findings from research analytics, national planning data, and grid integration studies.

Table 2 Projected Electricity Demand from EV Charging (TWh) [15]

Year	EV Penetration Scenario	Estimated EV Charging Demand (TWh)	% of Total Generation*
2025	Moderate growth	~4 TWh (early estimate)	~0.2–0.3%

2030	EV30@30 target	15–30 TWh	~1%–3%
2035	High adoption scenario	20–40 TWh	~6–8.7%
*Total generation assumption based on projected national energy targets.			

Challenges in Meeting EV-Driven Electricity Demand: While total electricity demand increases from EV adoption are modest relative to national consumption, several key challenges must be addressed:

1. Peak Load Stress and Grid Stability: Concentrated EV charging during existing peak demand periods can exacerbate grid stress, potentially leading to voltage issues and increased risks of outages—especially in congested urban grids.
2. Infrastructure Readiness: India's power infrastructure needs upgrades to support high EV penetration, including enhanced distribution networks and smart grid systems capable of real-time load management [15].
3. Matching Clean Generation: While EVs shift energy demand to electricity, the carbon intensity of that electricity matters. A grid heavily reliant on coal may undercut some of the emission benefits of EVs, unless renewable generation capacity scales up rapidly alongside EV adoption [17].

IV. EMISSION REDUCTION POTENTIAL

Tailpipe vs Lifecycle Emissions: EVs inherently eliminate tailpipe emissions, significantly improving local air quality and reducing NOx and $PM_{2.5}$ pollutants. Lifecycle assessments (LCAs) estimate that EVs can reduce CO_2 emissions by up to 38% compared to petrol vehicles, contingent on grid carbon intensity [18].

Role of Grid De-carbonization: The climate benefits of EVs depend significantly on electricity sources. EVs charged with coal-dominant power show limited emissions improvements compared to those charged with cleaner grids. Accelerated renewable capacity additions (e.g., solar and wind) can enhance EV emission benefits and create synergy between transport electrification and renewable power.

Table 3 Lifecycle CO_2 Emissions – EV vs ICE Vehicles

Vehicle Type	Lifecycle CO_2 Emission Trend	Emission Drivers
Petrol ICE	High	Fuel combustion
Diesel ICE	Very High	Fuel + local pollutants
EV (Coal-heavy grid)	Moderate	Grid emissions
EV (Renewable-rich grid)	Lower	Clean electricity

V. POLICY AND INFRASTRUCTURE DIMENSIONS

Renewable Integration: Aligning EV charging with periods of high renewable generation is critical for maximizing emission reductions and reducing marginal grid emissions. Renewable-integrated charging stations and solar-powered EV chargers reduce fossil fuel dependence and carbon intensity.

National Clean Energy Expansion: India has achieved significant renewable energy capacity additions, enhancing the potential for clean EV charging and emission reduction. Continued investments in renewable power infrastructure support the decarbonization of the electricity grid and improved climate benefits from EVs.

VI. CHALLENGES AND OPPORTUNITIES OF ELECTRIC VEHICLE ADOPTION IN INDIA

While electric vehicles (EVs) offer significant potential to reduce energy consumption, emissions, and oil dependency, their large-scale deployment in India faces several technical, economic, infrastructural, and policy-related challenges. At the same time, these challenges create new opportunities for innovation, grid modernization, renewable energy integration, and industrial growth.

Electricity Grid and Infrastructure Challenges: One of the primary challenges associated with EV adoption is the impact on power distribution networks. Although overall electricity demand increase due to EVs is moderate, localized grid stress can be severe, especially in urban areas with high EV concentration.

Uncoordinated EV charging during peak hours may lead to:

- Transformer overloading
- Voltage fluctuations
- Increased distribution losses

Studies indicate that peak demand could rise by 15–25% in certain urban feeders under high EV penetration without smart charging strategies [21], [22]. India's distribution infrastructure, already facing losses exceeding 20% in some states, requires significant upgrades to accommodate EV loads [23].

Charging Infrastructure Deficit: Despite rapid growth in EV sales, public charging infrastructure remains insufficient. As of recent assessments, India has far fewer public chargers per EV compared to global benchmarks, leading to range anxiety and reduced consumer confidence.

Challenges include:

- Uneven geographic distribution of chargers
- Lack of fast-charging stations on highways

- Grid connectivity constraints for high-power chargers

Research highlights that charging infrastructure availability is one of the strongest determinants of EV adoption rates [24].

Battery Technology and Supply Chain Issues: Lithium-ion batteries constitute 30–40% of total EV cost, making vehicles expensive for many Indian consumers [25]. Furthermore, India is highly dependent on imported battery raw materials such as lithium, cobalt, and nickel, raising concerns about supply security and price volatility.

Additional challenges include:

- Limited domestic battery manufacturing capacity
- Environmental concerns related to battery disposal and recycling
- Performance degradation under high ambient temperatures

Life-cycle studies emphasize that battery manufacturing contributes significantly to EV lifecycle emissions, especially if powered by fossil-fuel-based electricity [26].

Economic and Consumer-Related Barriers: High upfront cost remains a major deterrent, particularly for passenger cars. Although total cost of ownership (TCO) for EVs is often lower over vehicle lifetime, initial purchase price strongly influences buyer decisions [27].

Other barriers include:

- Limited model availability in certain segments
- Low consumer awareness
- Uncertainty regarding resale value

Opportunities Arising from EV Adoption:

Despite these challenges, EV deployment presents significant opportunities that can accelerate India's transition toward a sustainable energy and transport system.

Table 4 Opportunities Enabled by EV Adoption

Opportunity Area	Key Benefits
Energy Security	Reduced oil imports
Renewable Integration	Lower curtailment, cleaner charging
Economy	Jobs, domestic manufacturing
Environment	Lower emissions, better air quality
Power Sector	Smart grid development

VII.CONCLUSION

Electric vehicle (EV) adoption has the potential to play a pivotal role in transforming India's transport and energy sectors by reducing dependence on imported fossil fuels, improving energy efficiency, and mitigating environmental pollution. This review highlights that although large-scale EV penetration will increase electricity demand, the overall impact on national energy consumption

remains manageable, particularly when supported by planned capacity expansion and grid modernization. The superior efficiency of EVs compared to internal combustion engine vehicles leads to significant reductions in final energy use per kilometer, while the elimination of tailpipe emissions offers substantial improvements in urban air quality. The emission reduction potential of EVs is strongly influenced by the electricity generation mix. Even under current coal-dominated conditions, EVs provide net benefits in terms of local air pollutant reduction; however, their full climate mitigation potential can only be realized through accelerated integration of renewable energy into the power grid. Challenges related to charging infrastructure, battery cost, grid stress, and supply chain dependence remain critical but also present opportunities for innovation, domestic manufacturing, and smart grid development.

Future research should focus on high-resolution modeling of EV charging behavior, assessment of real-world grid impacts at the distribution level, and life-cycle emission analysis under evolving electricity mixes. Further work is also required on battery recycling, second-life applications, and vehicle-to-grid technologies to enhance system flexibility and sustainability. An integrated policy framework aligning transport electrification with renewable energy expansion and grid digitalization will be essential for maximizing the long-term energy and environmental benefits of EV adoption in India.

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