International Journal of Research in Management & Social Science
Volume 13, Issue 4 October - December 2025
ISSN 2322 - 0899

ARE EVS REALLY THE FUTURE OF INDIA?

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ABSTRACT
India's shift toward sustainable mobility has accelerated interest in electric vehicles (EVs) as an alternative to internal combustion engine (ICE) vehicles, driven by urbanization, worsening air quality, and global climate commitments. Drawing on forty recent studies, this paper evaluates the environmental, economic, technological, and infrastructural factors shaping India's EV transition. Although EVs offer clear benefits—lower emissions, higher energy efficiency, and reduced long-term operating costs—their adoption remains constrained by high initial prices, inadequate charging infrastructure, battery-related limitations, and environmental impacts linked to mineral extraction and e-waste. Furthermore, India's coal-dominated energy mix and fragmented supply chains pose additional barriers to large-scale electrification. The analysis suggests that hybrid electric vehicles (HEVs and PHEVs) provide a practical transitional solution, offering lower emissions without the range anxiety and infrastructural demands of fully electric models. The study concludes that coordinated policy reforms, technological innovation, domestic battery manufacturing, renewable-energy integration, and sustainable recycling systems are essential to building a resilient and equitable path toward clean mobility in India.
Keywords: *Internal Combustion Engine (ICE), Electric Vehicles (EVs)*

INTRODUCTION
The transition toward sustainable transportation has become one of the most pressing priorities of the twenty-first century. Electric vehicles (EVs) have emerged as a potential solution to address environmental degradation, fossil fuel dependence, and climate change. Over the past decade, India has embraced this global movement through policy reforms, public awareness campaigns, and industrial innovation. Despite these advancements, the practicality of EVs as the dominant mobility solution for India remains under debate. Factors such as high initial cost, inadequate charging infrastructure, and dependence on imported battery materials continue to pose significant challenges.
This paper analyzes the future of EVs in India by examining environmental, economic, and technological aspects derived from forty recent studies. It further discusses the limitations of EVs and highlights hybrid electric vehicles (HEVs) as a more balanced transitional technology for the Indian context.

2. LITERATURE REVIEW

2.1. Global Warming and Climate Change
Rising global temperatures and increasing greenhouse gas emissions have intensified the urgency to adopt sustainable transportation. The scientific and political focus on climate change has been growing since the late twentieth century, emphasizing that the threat is no longer distant but immediate [1]. Traditional internal combustion engine vehicles (ICEVs) account for nearly one-quarter of global CO_2 emissions, making them a significant contributor to global warming [2]. The transport sector's dependence on fossil fuels has resulted in recurring natural disasters, sea-level rise, and ecosystem disruption [2]. International agencies such as the United Nations Intergovernmental Panel on Climate Change advocate for global multilevel governance to mitigate these impacts [1]. Nations worldwide are thus under pressure to shift from ICEVs to low-emission alternatives. In this context, EVs have been positioned as one of the key enablers of a low-carbon future due to their ability to reduce operational emissions [31]. India, with its rapidly urbanizing population and worsening air quality, stands at a critical juncture to adopt greener mobility.

2.2 The Growing Popularity and Appeal of Electric Vehicles
EVs have gained global attention for their environmental friendliness, operational efficiency, and technological innovation. Their electric propulsion eliminates tailpipe emissions, directly improving urban air quality and public health [31]. Moreover, EVs are quieter than ICE vehicles, offering smoother and vibration-free rides that enhance driving comfort [20][23].

From an efficiency standpoint, EVs convert over 77% of the electrical energy from the grid into wheel power, compared with roughly 30% for gasoline vehicles [20]. Their minimal maintenance, regenerative braking, and government incentives make them financially appealing in the long term [30]. Government policies and subsidies have accelerated their adoption, supported by consumer enthusiasm and

growing environmental consciousness [35]. In India, initiatives such as FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) and state-level incentives have encouraged both manufacturers and consumers to transition toward electric mobility [36]. Furthermore, technological innovations such as smart charging, energy-efficient batteries, and integration with renewable energy sources enhance their appeal as sustainable transport solutions [20]. These advantages have shaped public perception that EVs represent the inevitable future of the automotive industry.

While the appeal of electric vehicles is undeniable—driven by their environmental promise, innovative technology, and government incentives—their widespread adoption is far from straightforward. Beneath the surface of this enthusiasm lie complex challenges that extend across economic, environmental, and infrastructural dimensions. Understanding these limitations is essential to evaluate whether EVs can genuinely serve as the long-term mobility solution for India. The following section examines these critical barriers in depth, highlighting the economic constraints, ecological implications, and technical limitations that accompany the transition toward electrification.

2.3. Disadvantages and Challenges

2.3.1 Economic Barriers

Despite their benefits, EVs face major economic constraints. The initial cost of an EV remains significantly higher than that of a comparable ICE vehicle due to expensive battery packs that constitute 30–60% of total vehicle cost [27]. Battery replacement can reach up to $20,000 depending on model and warranty terms [27].

Although operational costs are lower, battery degradation and depreciation rapidly reduce an EV's resale value. Studies show that EVs depreciate faster than gasoline cars—up to 13.9% annually compared with 10.4% for ICEVs [16]. Within five years, an average EV may lose nearly half its value [17]. Uncertainty regarding battery lifespan and replacement further discourages potential buyers [4]. In India, where consumer income levels are lower and financing options limited, these costs become critical deterrents [3]. Additionally, rising electricity tariffs, such as those recently observed in Tamil Nadu, can further offset operational savings [10].

2.3.2 Environmental and Social Concerns

Although EVs are promoted as "zero-emission," their environmental impact extends beyond vehicle operation. Lithium-ion battery (LIB) production involves extensive mining of lithium, nickel, and cobalt, generating significant ecological disruption [11]. In 2023 alone, an estimated 7,484 megatonnes of rock were mined globally to meet battery demand [11].

These mining operations often occur under poor labor conditions, with reports linking raw material extraction to hazardous child labor practices [13]. Improper disposal of e-waste also releases toxic pollutants such as PCBs and dioxins into ecosystems [14].

Battery degradation is inevitable over time, and recycling remains inefficient. Currently, less than 5% of lithium batteries are recycled, even though up to 95% of key materials could be recovered under ideal conditions [19].

India's lack of comprehensive e-waste management infrastructure amplifies these concerns. Rapid EV adoption without adequate recycling systems could exacerbate socio-environmental harm [33][32].

2.3.3 Technical Limitations

Battery efficiency, lifespan, and fire safety remain major technical challenges. Lithium-ion batteries require stringent thermal management to prevent overheating and ensure durability [6]. However, under abusive conditions or accidents, thermal runaway can trigger fires and toxic gas emissions that are difficult to extinguish [18].

EV performance also varies drastically under real-world conditions. Standardized testing cycles often overestimate battery range because they exclude variables like terrain, payload, and temperature [26]. In Nordic climate tests, real-world range was found to be substantially lower than manufacturer claims [39], while highway driving further decreases energy efficiency [40].

Additionally, battery corrosion due to flooding or moisture infiltration can compromise safety and performance [21].

2.3.4 Infrastructure and Operational Issues

India's charging infrastructure is still nascent. The absence of reliable, accessible charging stations discourages consumers and hinders growth [5]. Poor maintenance, theft, and mismatched online data have led to nearly 84%

of Delhi's chargers being non-functional in a recent survey [29]. Inefficient charging-station placement may also strain the power grid, causing voltage instability and power loss [5]. Moreover, inadequate real-time data and parking encroachment by ICE vehicles further disrupt accessibility [29].

Energy tariffs and fixed costs for high-tension connections make fast-charging operations economically unsustainable [10]. The lack of coordinated infrastructure planning limits large-scale EV deployment, particularly across non-urban India.

While these challenges reveal the complex realities of India's electric mobility transition, they also highlight areas where strategic innovation and policy intervention can yield transformative results. The limitations in cost efficiency, infrastructure readiness, environmental safety, and consumer confidence emphasize that India's EV ecosystem is still evolving rather than failing. Each barrier—from inadequate charging networks to unsustainable supply chains—offers an opportunity for technological advancement and regulatory reform.

3. METHODOLOGY

This study employs a quantitative descriptive research design to assess public perceptions, acceptance levels, and concerns regarding electric vehicles (EVs) in India. A quantitative approach is appropriate because it enables the systematic measurement of attitudes, preferences, and behavioural intentions using numerical data. Information was gathered through a structured online questionnaire created and distributed via Google Forms, allowing respondents from urban and semi-urban regions to participate conveniently.

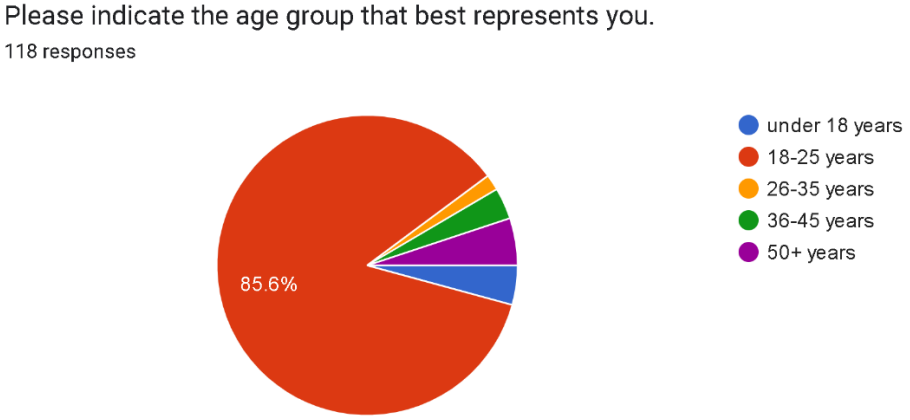
A total of 118 respondents were selected using convenience sampling, targeting students, working professionals, and active vehicle users. This diverse sample provided broader insight into awareness levels, perceived benefits, perceived challenges, and purchase intentions related to EV adoption. The research instrument included demographic items (age, gender, occupation), awareness-based questions, multiple-choice items, and Likert-scale statements (1 = Strongly Disagree to 5 = Strongly Agree) that measured key constructs such as perceived advantages of EVs, infrastructural concerns, and preference between EVs, hybrid vehicles, and internal combustion engine (ICE) vehicles.

Collected data was analysed using descriptive statistical techniques, including frequency distribution, percentage analysis, mean scoring, and cross-tabulation where relevant. Visual tools such as pie charts and bar charts supported the interpretation of results by illustrating respondent demographics and choice patterns. The narrative discussion of these visuals provides a clear understanding of public sentiment toward EV adoption in the Indian context.

4. DATA ANALYSIS AND INTERPRETATION

4.1 Demographic Characteristics

The study gathered responses from individuals aged 18 to 50+ years, providing a broad representation of adult vehicle users. Most respondents currently drive internal combustion engine (ICE) vehicles (≈86%), while only a small share own EVs (≈11%) or hybrid cars. However, preference patterns show a noticeable shift in attitude: although ICE vehicles still hold the highest preference (≈45%), a growing proportion of participants express interest in electric vehicles (≈28%) and hybrids (≈27%), indicating a gradual openness toward cleaner mobility options despite limited current adoption.



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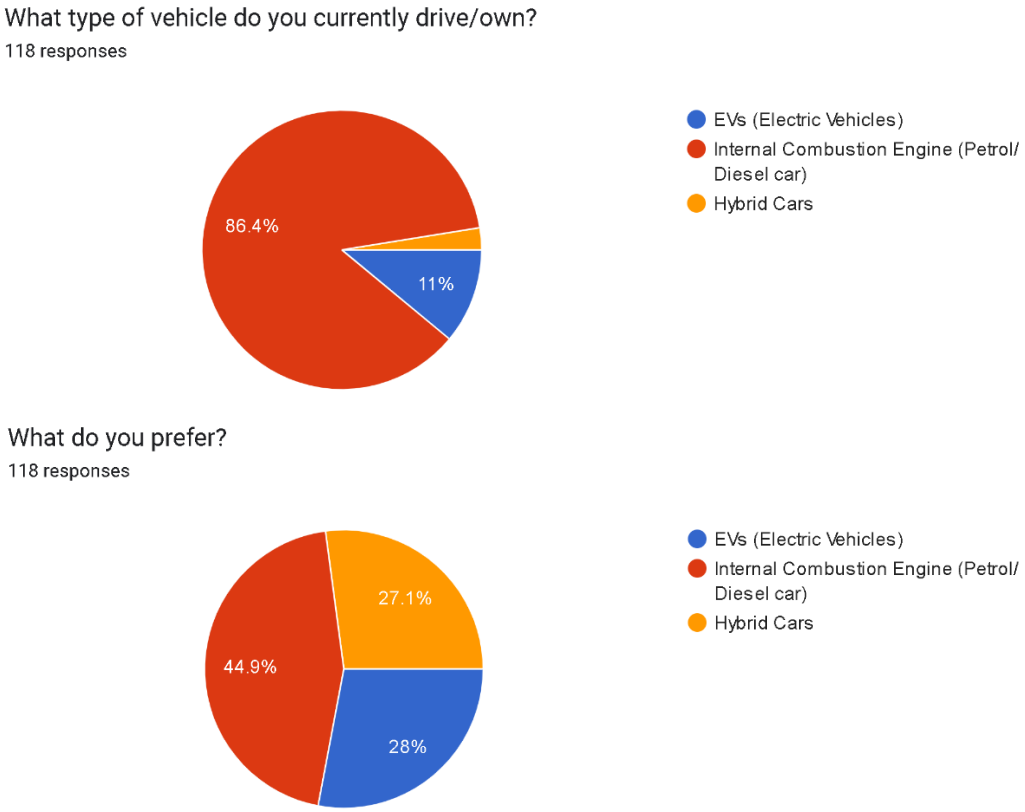
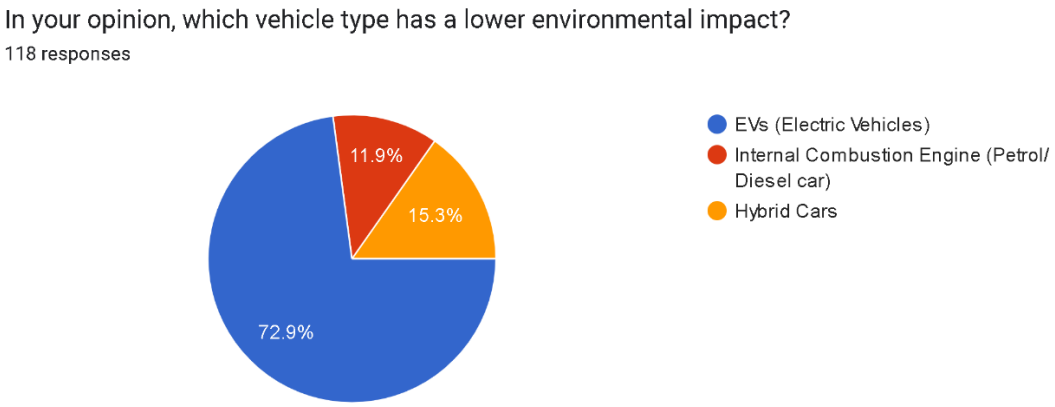
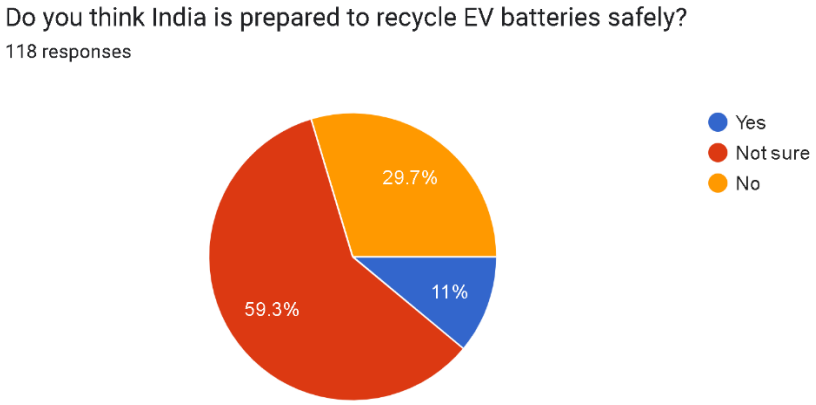
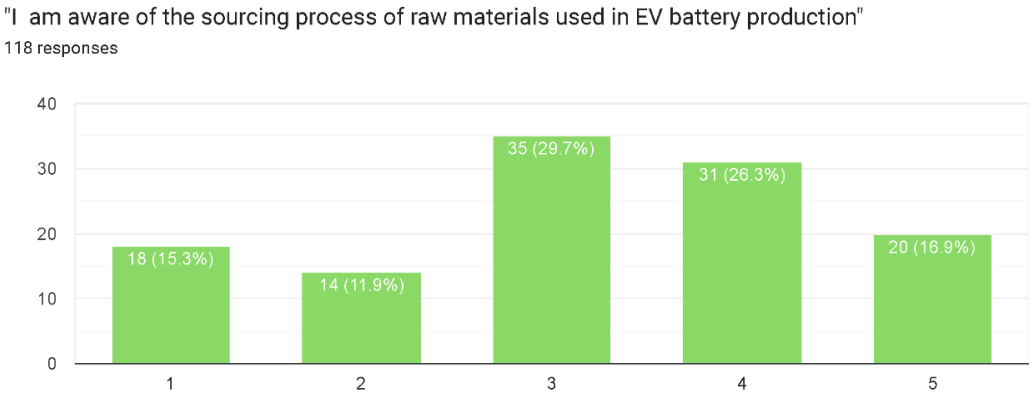


4.2 Awareness and Knowledge Data

The awareness analysis shows that a strong majority of respondents (72.9%) recognize electric vehicles as the most environmentally friendly option, indicating high public understanding of EVs' ecological benefits. However, when asked about India's readiness to recycle EV batteries safely, responses reflected uncertainty—only 11% believed the country is prepared, while 59.3% were unsure and 29.7% felt India is not ready. This contrast suggests that although people are not aware of EVs' environmental disadvantages, awareness of battery recycling infrastructure and sustainability challenges remains limited. Overall, respondents lack clarity about India's capacity to manage EV-related waste responsibl







4.3 User-Reported Drawbacks of Electric Vehicles and Preferences

The findings highlight several core barriers affecting EV acceptance in India. Infrastructural limitations remain a major challenge, with only 22.9% of respondents having a charging station within 1 km, while most reported distances of 1–5 km (34.7%) or 6–10 km (17.8%); additionally, 24.6% were unaware of any nearby station, underscoring significant accessibility gaps. Cost- and battery-related concerns were widely noted, including high purchase prices, maintenance expenses, uncertainties about battery lifespan, replacement needs, and safety risks such as thermal incidents. Environmental apprehensions regarding lithium-ion battery production, mining impacts, and inadequate recycling systems also contributed to user hesitation. Performance issues remain prominent, as 74.6% reported experiencing or hearing of reduced range or battery degradation, indicating doubts about long-term reliability. Moreover, experiential preferences continue to influence perceptions: 51.7% felt less connected to EVs due to the absence of engine sound, suggesting that emotional and sensory factors also shape consumer acceptance. Overall, infrastructural gaps, economic constraints, environmental concerns, performance issues, and driving experience collectively form substantial barriers to broader EV adoption in India.

The responses indicate that three key factors shape consumers' decisions to purchase an electric vehicle. Environmental impact is the strongest driver, influencing 67 respondents who view EVs as a cleaner and more sustainable alternative. Technology-related features—such as advanced safety systems, modern design, and innovative driving experiences—motivate 60 of participants. Cost remains a major consideration for 55

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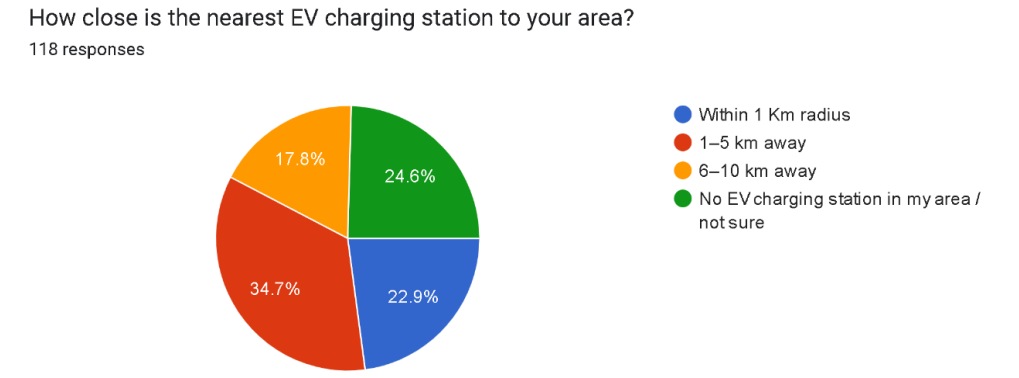
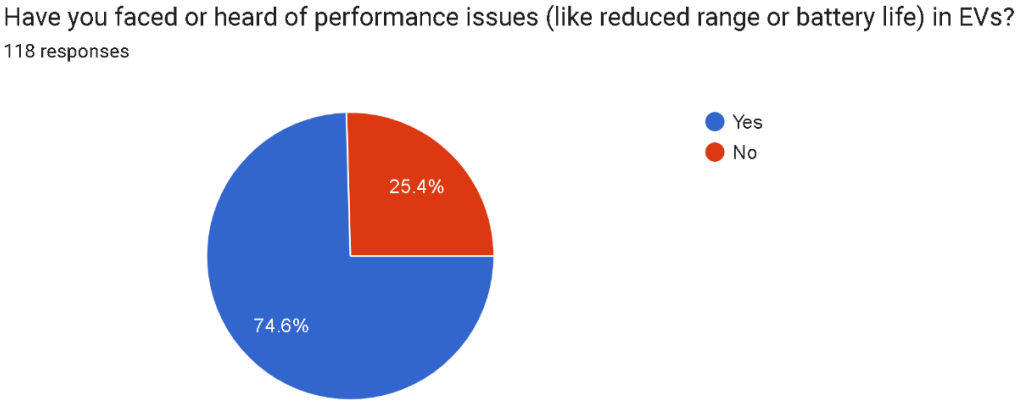
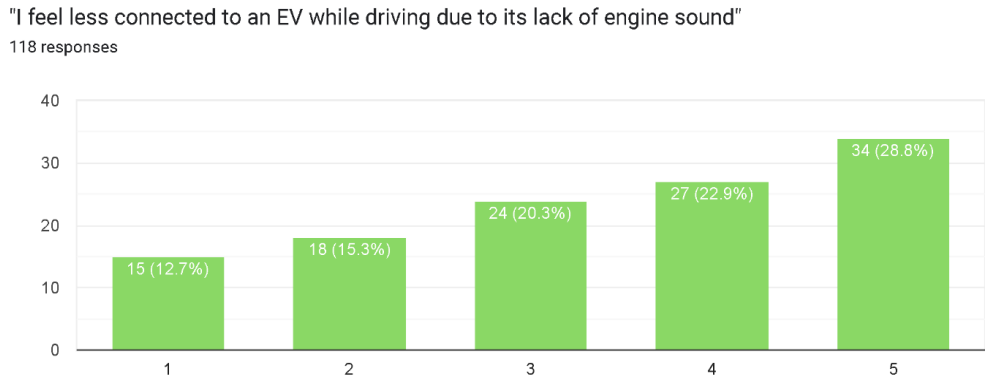
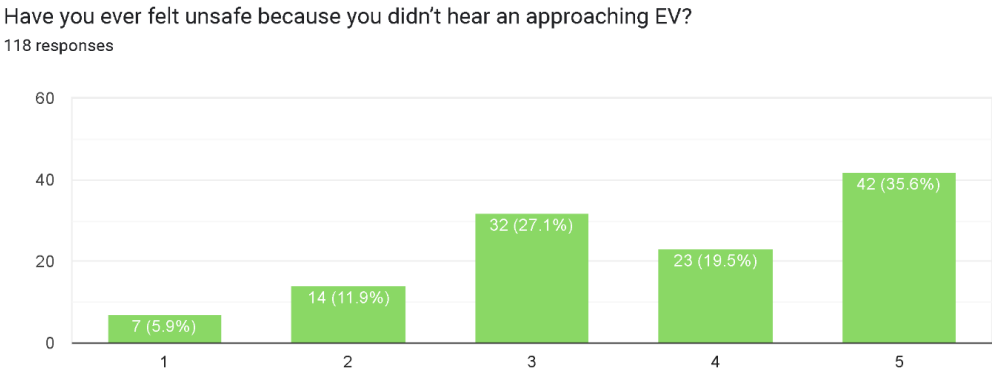
respondents, reflecting concerns about high upfront prices and long-term affordability. Overall, environmental benefits emerge as the primary motivator, followed closely by technological appeal and cost considerations.









4.4 Perceptions of EV Charging Duration and Convenience

The findings indicate that battery-charging convenience is a critical factor influencing EV adoption. A majority of respondents (over 60%) rate the availability of fast-charging stations as highly significant in their purchase decision, reflecting strong dependence on reliable charging infrastructure. Charging-time expectations are also clear: most users are only willing to wait between under an hour to 2–4 hours, while very few find overnight

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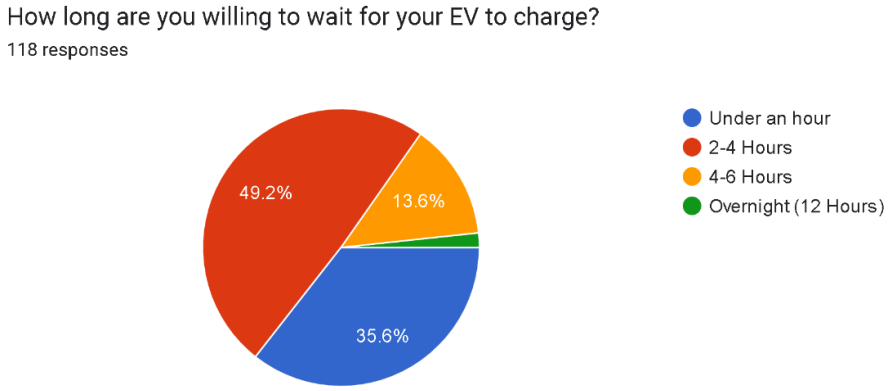
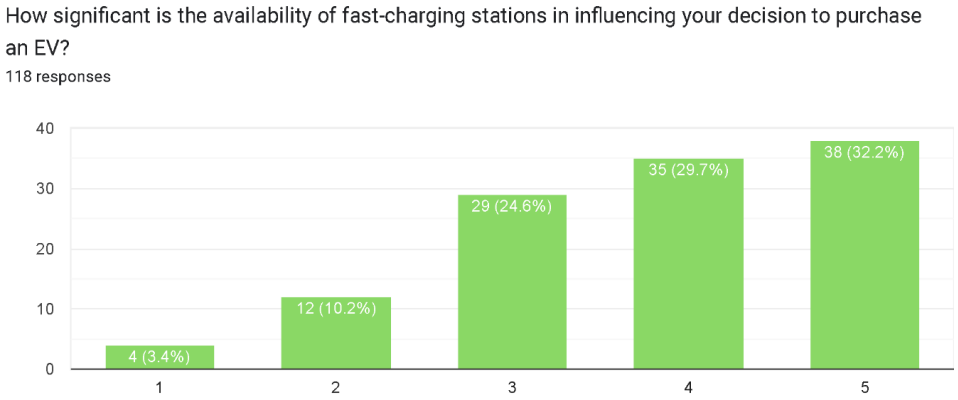
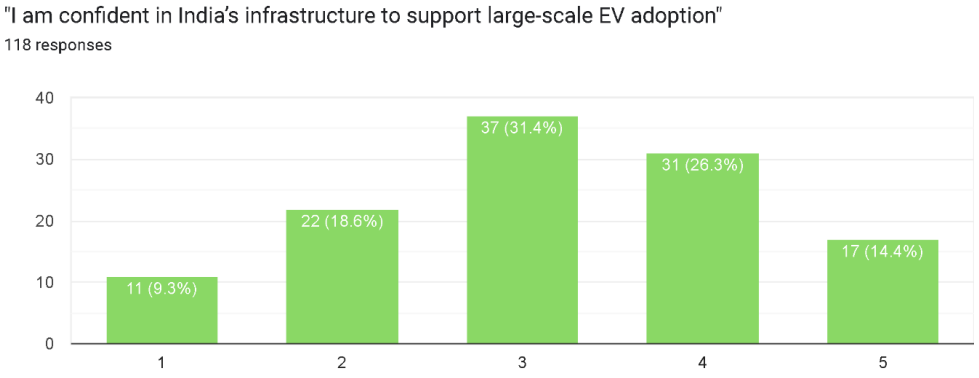
charging acceptable. Overall, the results show that consumers prefer widespread fast-charging access and shorter charging durations, underscoring the need for robust, time-efficient charging networks to strengthen confidence in EV ownership.





4.5 Perceptions of India's Infrastructure Preparedness for the EV Transition

The survey results indicate a moderate level of public confidence in India's readiness to support large-scale EV adoption. Most respondents selected mid-range ratings, with the highest share (31.4%) choosing 3, suggesting cautious optimism about current infrastructure. While 26.3% rated confidence at 4 and 14.4% at 5—showing growing trust in India's progress—over a quarter of participants (27.9%) expressed low confidence by choosing 1 or 2. Overall, the data reflects that although India is moving in the right direction, significant infrastructure improvements are still needed to fully support widespread EV adoption.



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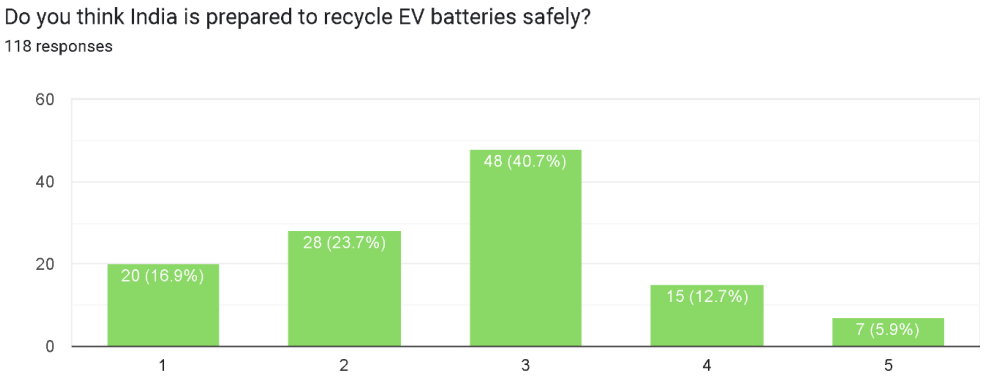

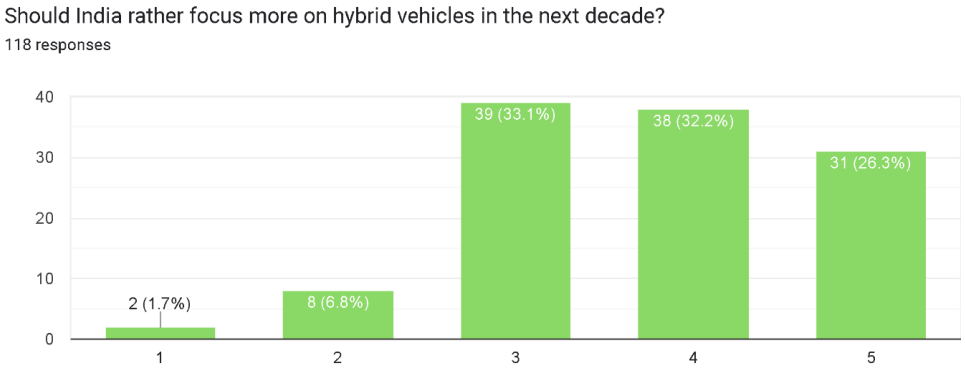

5. PATH FORWARD— DISCUSSION

5.1 Policy and Investment Strategies

Government policy remains the strongest lever in shaping India's EV future. Comprehensive regulatory support, financial incentives, and infrastructure investment are crucial to offset current economic and technical challenges [3][36]. India's national EV policy aims for 100% light-duty electrification by 2030, reflecting both environmental and industrial ambitions [34].
Targeted subsidies on battery production, import-duty exemptions, and tax benefits for EV buyers have encouraged manufacturers to invest in localized assembly lines [8]. Yet, dependence on imported raw materials such as lithium, cobalt, graphite, and nickel continues to expose the Indian market to price volatility and supply disruptions [8][9].

Developing domestic gigafactories, supported by public-private partnerships, can stabilize costs and create employment. Such facilities would also strengthen India's strategic autonomy in the global EV value chain [9]. However, these ventures require substantial long-term investment, robust environmental regulations, and transparent governance.

5.2 Technological Advancements

Innovation in battery technology and vehicle design is key to improving range, reliability, and affordability. Smart hybrid thermal-management systems have shown potential to extend battery lifespan and performance while reducing energy loss [6]. Continuous advances in lithium-ion and next-generation chemistries such as solid-state batteries promise higher energy density and lower degradation rates [15].

Research also emphasizes the importance of testing vehicles under real-world conditions rather than controlled laboratory cycles to obtain accurate performance data [26]. Enhanced drive-cycle modeling would ensure more realistic range estimates, boosting consumer confidence.
Material science developments, including 2D-material coatings and improved tribology, can reduce friction, corrosion, and maintenance costs in EV powertrains [2]. Meanwhile, lightweight designs and regenerative systems further enhance energy efficiency and vehicle safety.

5.3 Recycling, Supply Chain, and Resource Management

Recycling and circular-economy strategies are vital to mitigating the environmental footprint of battery production. Under ideal circumstances, recycling could recover up to 95% of valuable materials and meet 53% of lithium demand by 2040 [19].

Sustainable mining, ethical sourcing, and local recycling infrastructure would reduce dependency on imports while minimizing environmental degradation [24]. Effective collection systems and battery-tracking mechanisms can prevent unsafe disposal and encourage reuse in secondary applications such as stationary energy-storage systems [37].

However, India currently lacks coordinated e-waste management for EV batteries [33]. Establishing national guidelines and financial incentives for recyclers could transform waste into an opportunity for industrial innovation and resource conservation [14][19].

5.4 Renewable Energy Integration

For EVs to be truly sustainable, the electricity used to charge them must come from renewable sources. The environmental benefits of EVs diminish if the grid remains coal-dominated [28][34]. Integrating renewable energy (RE) with smart charging enables a balance between energy supply and demand while reducing grid congestion [20].

Daytime solar charging, time-of-use tariffs, and vehicle-to-grid (V2G) technologies can transform EVs into distributed energy resources that support grid stability [20]. The adoption of clean energy generation, particularly solar and wind, would ensure that EVs contribute to net-zero emission goals rather than shifting emissions from tailpipes to power plants.

In this context, India's expansion of renewable capacity under national energy missions provides a strong foundation for sustainable mobility—if coupled with intelligent energy management and supportive policies.

Addressing these interconnected issues requires a holistic approach that aligns government policy, industrial capability, and environmental responsibility. With targeted investment, improved domestic production, and sustainable energy integration, India can overcome these obstacles and redefine its mobility landscape toward long-term resilience and inclusivity.

6. CONCLUSION

Why Hybrid Cars may be the future

Hybrid electric vehicles (HEVs) and plug-in hybrids (PHEVs) combine the benefits of electric propulsion with the practicality of internal combustion engines, making them ideal transitional technologies for India. They reduce greenhouse-gas emissions by up to 30–35% compared with conventional vehicles while avoiding range anxiety [28][15].

PHEVs can operate purely on electricity for short urban trips and switch to fuel for longer journeys, thereby maintaining flexibility in regions lacking adequate charging infrastructure [15][40]. Their dual-energy systems optimize fuel efficiency and reduce dependence on charging networks that are still under development [3].

From a life-cycle perspective, hybrids produce fewer emissions in coal-dependent grids because they rely partly on conventional fuel rather than drawing all energy from fossil-powered electricity [28][34]. Additionally, hybrid systems mitigate battery-degradation issues, as the internal combustion engine supports propulsion under high-load conditions, extending battery life [6][15].

Given India's economic realities, infrastructural limitations, and mixed energy mix, hybrids represent a practical bridge toward full electrification. They allow manufacturers to refine technology, governments to expand renewable infrastructure, and consumers to adopt greener transport without facing prohibitive costs or range limitations.

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