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Barriers to Electric Vehicle Adoption in India: A Comparative Review and Future Growth Prospects

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Abstract
India's transportation sector, which heavily relies on fossil fuels, contributes significantly to air pollution and greenhouse gas emissions. The adoption of electric vehicles (EVs) is seen as a critical solution to mitigate these environmental impacts. This paper explores the current state of EV adoption in India, analyzing key barriers and opportunities for growth. Despite government initiatives such as the National Electric Mobility Mission Plan (NEMMP) and the FAME schemes, EV adoption remains slow, comprising less than 1% of the total vehicle market. The primary barriers include high upfront costs, limited charging infrastructure, range anxiety, and lack of standardized charging ports. This paper also compares EVs with traditional internal combustion engine (ICE) vehicles, highlighting EVs' advantages in terms of environmental impact and long-term cost savings. However, ICE vehicles remain dominant due to their lower purchase price and well-established refuelling infrastructure. The review categorizes major barriers into physical, technical, financial, and policy-related challenges, while also identifying opportunities for growth, such as improvements in battery technology, expansion of charging infrastructure, and emerging business models. With focused efforts to overcome these challenges, India has the potential to lead in electric mobility and contribute to global climate goals.

Keywords Electric Vehicles (EVs), traditional vehicles, adoption, barriers, government initiatives

1. Introduction

India's transportation sector, which relies heavily on fossil fuels, contributes significantly to air pollution and greenhouse gas (GHG) emissions (Dhankhar et al., 2024b). In urban areas, vehicular emissions are a primary source of air pollution, with transportation accounting for nearly 12% of India's carbon dioxide emissions (IEA, 2023). As the third-largest emitter of GHGs globally, India faces urgent environmental challenges that threaten not only its ecological balance but also public health and economic development (Chateau et al., 2023). With rapid urbanization and growing vehicle ownership, addressing these environmental issues has become increasingly important. In this context, the adoption of electric vehicles (EVs) is seen as a pivotal strategy to mitigate the environmental impact of transportation (Chhikara et al., 2021). EVs provide a more energy-efficient and environmentally friendly alternative to conventional internal combustion engine (ICE) vehicles, as they are propelled by electricity rather than petrol or diesel. (Dhankhar et al.,2024a). India has the potential to substantially reduce its carbon footprint, lower urban pollution levels, and fulfil its climate commitments under the Paris Agreement by transitioning to EVs (Arora et al., 2023).The government has recognized the critical role of EVs in sustainable transportation and has implemented several policy measures to promote their adoption. Initiatives such as the National Electric Mobility Mission Plan (NEMMP), launched in 2013, and the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, introduced in 2015, are designed to boost the EV ecosystem in the country

(Dhankhar et al., 2024a). The FAME-II scheme, launched in 2019, further strengthened the government's commitment by offering financial incentives for EV purchases, as well as for the development of charging infrastructure (*National Automotive Board,2024)*. These policy measures aim to achieve a target of 30% EV sales by 2030, which is seen as a crucial milestone in India's journey toward sustainable mobility (Chaturvedi et al., 2022).

Despite these efforts, the adoption of EVs in India remains at a nascent stage, with EVs comprising less than 1% of the total vehicle market (Shankar & Kumari, 2019). There are numerous obstacles that impede the widespread adoption of electric vehicles in the nation.. First, the high upfront cost of EVs, primarily due to the expensive lithium-ion batteries, makes them less affordable for the average consumer compared to traditional ICE vehicles (Goel et al.,2021). Furthermore, operational costs for EVs are lower due to cheaper electricity and reduced maintenance, the initial investment acts as a major deterrent for many potential buyers (Singh et al., 2021).The absence of a comprehensive and dependable charging infrastructure constitutes a substantial obstacle (Kumar & Alok, 2020). The government's proposal for a countrywide network of charging stations is hindered by poor infrastructure, particularly in semi-urban and rural regions. Range anxiety, defined as the fear of reducing battery power without available charging stations, is a significant problem for prospective electric vehicle adopters (Pevec et al., 2019). The problem is intensified by India's diverse geography, necessitating a comprehensive and resilient charging network to serve both urban and rural populations. This review paper aims to explore the current state of EV adoption in India by examining key government policies, the major challenges hindering adoption, and the opportunities for future growth. The paper will provide a comprehensive analysis of the EV landscape in India and offer insights into how the country can overcome existing barriers to become a global leader in sustainable transportation.

2. Electric Vehicle Vs Traditional Vehicles

The decision to adopt electric vehicles (EVs) over traditional internal combustion engine (ICE) vehicles involves weighing several key factors. Each type of vehicle comes with its own advantages and challenges, influencing consumer preferences and policy decisions. Figure 1 shows the difference between EVs and Traditional Vehicles

2.1. Environmental Impact

EVs are often considered the environmentally friendly alternative due to their zero tailpipe emissions, which help reduce air pollution and greenhouse gases (E-Amrit,2024). In contrast, ICE vehicles rely on fossil fuels, which produce significant carbon dioxide and other harmful emissions. However, the environmental benefit of EVs depends on the energy source for electricity generation. In countries where coal is a major source of electricity, the overall environmental gain from EVs may be reduced.

*2.*2. Cost of Purchasing and Maintenance

While EVs typically have a higher upfront cost due to the expensive lithium-ion batteries, they offer lower long-term ownership costs. EVs have fewer moving parts, which lead to lower maintenance costs, and the cost per kilometer driven is generally lower due to cheaper electricity compared to gasoline or diesel. ICE vehicles, on the other hand, are initially cheaper to purchase but tend to have higher fuel and maintenance costs over time.

2.3. Range and Refuelling

Traditional ICE vehicles have a clear advantage when it comes to range and refuelling infrastructure. A typical gasoline or diesel car can travel longer distances on a full tank, and refueling is quick and convenient, thanks to an extensive network of fuel stations. EVs, while improving in terms of range, still face "range anxiety" due to limited charging infrastructure and the longer time it takes to charge compared to refueling an ICE vehicle.

*2.*4. Noise Levels

One of the most noticeable differences between EVs and traditional ICE vehicles is noise. EVs operate almost silently, making them ideal for reducing noise pollution in urban environments. This quiet operation enhances comfort for both drivers and passengers. However, this lack of engine noise can pose a safety risk to pedestrians and cyclists, particularly in congested areas or at low speeds. As a result, regulations in some countries require EVs to emit artificial sounds at low speeds to alert others to their presence. In contrast, ICE vehicles are noisier due to their internal combustion engines, contributing to both urban noise pollution and a more aggressive driving experience.

2.5. Availability and Market Adoption

ICE vehicles currently dominate the global market, with a well-established manufacturing and supply chain. They are available in a wide variety of models, from budget-friendly options to luxury cars, and enjoy widespread consumer familiarity. EVs, on the other hand, are still a growing segment, with limited model availability in many markets. However,

governments around the world are pushing for greater EV adoption through incentives, and the market is expected to grow as battery technology improves and costs decrease.

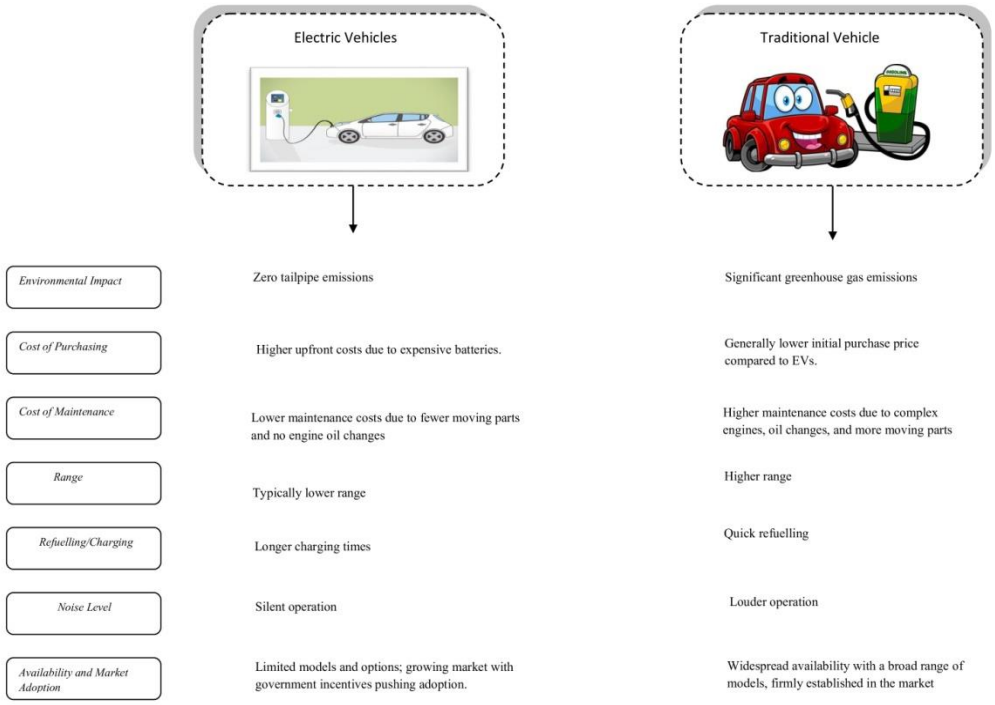

Fig.1. electric vehicles *VS* traditional vehicles

3. Major Barriers for EV adoption

Major Barriers for EV adoption can be divided into different parts such as Physical barrier, Technical barrier, financial barrier and Policy barrier. Figure 2 shows the barriers the act as a obstacles in EV adoption.

3.1 Physical Barriers

3.1.1 Inadequate Charging Infrastructure

The limited availability of public charging stations is one of the most critical physical barriers to EV adoption in India (Ashok et al., 2022). According to the Ministry of Heavy Industries (2024), there are currently only 12,146 EV charging stations across the country. This number is disproportionately low compared to the growing population of EVs, particularly in rural and semi-urban areas (Carlton & Sultana, 2022). The lack of charging infrastructure outside major cities contributes to range anxiety, discouraging potential EV buyers from committing to electric mobility. That's why, without widespread and easily accessible charging points, potential EV users remain reluctant to switch from conventional vehicles, and drivers must carefully plan their trips.

3.1.2 Range Anxiety

Range anxiety is the fear that an electric vehicle will not have sufficient battery charge to reach the nearest charging point (Pevec et al., 2019), especially in regions where charging infrastructure is sparse. This psychological barrier is directly linked to the physical availability of charging stations. A majority of battery electric vehicles (BEVs) have a driving range of less than 250 kilometres per charge (Goel et al.,2021). However, some of the most recent models are capable of providing up to 400 kilometres (*India Environment Portal*). Due to the availability of internal combustion engines that run on liquid fuel, plug-in hybrid electric vehicles (PHEVs) currently have a range of at least 500 km. So before planning a trip in an EV, drivers must consider their concerns about the vehicle's range.

3.1.3 Land Availability for Charging Stations

The establishment of charging stations necessitates appropriate land, which can be challenging to obtain in highly populated urban regions and expensive in major metropolitan areas (Csiszár et al., 2019). Additionally, land allocation issues can lead

to delays in setting up large-scale charging infrastructure projects (Unterluggauer et al., 2022). These challenges further slow down the development of a robust charging network across India.

3.1.4 Limited Power Grid Capacity

Many parts of India, particularly rural areas, suffer from unreliable or insufficient power supply (Harish et al., 2014). The installation of charging stations requires not just the physical space but also a robust and stable electricity grid to handle the increased demand for power (Nutkani & Lee,2022). The current power grid in many regions is not fully equipped to support widespread EV charging infrastructure, which limits the growth of a viable charging network.

3.1.5 Lack of Standardization in Charging Ports

The absence of a standardized charging port system across different EV manufacturers leads to compatibility issues for charging stations (Asanov,2023). This inconsistency means that a station installed for one type of vehicle may not serve another, creating a fragmented infrastructure (Bulawa et al.,2024). As a result, EV users face difficulties in finding suitable charging points, further limiting their convenience and confidence in EV usage.

3.2 Technical Barriers

3.2.1 Battery Cost

The cost of lithium-ion batteries is a major technical obstacle to electric vehicle adoption Goel et al.,2021). Batteries make up approximately 40% to 50% of the overall expense of an EV, making their price significantly higher than that of internal combustion engine (ICE) vehicles (*Slowing U.S. EV Sales, High Manufacturing Costs Will Drive Search for Efficiency*, 2024). Despite a notable decline in battery prices, they remain high for the price-sensitive Indian market (Electric Vehicle Battery Prices Are Falling Faster Than Expected,2023). The lack of domestic battery production further exacerbates this issue, driving up overall costs and slowing the affordability of EVs.

3.2.2 Slow Charging Times

One of the key technical limitations of current EV technology is the time it takes to charge a vehicle. Even with advancements in fast-charging technology, fully recharging an EV can take significantly longer than refuelling a traditional petrol or diesel vehicle (Goel et al.,2021).This slow charging time is inconvenient for consumers, especially in fast-paced urban environments where quick refuelling is essential. That's why without widespread fast-charging infrastructure, this issue becomes a major technical barrier to EV adoption.

3.2.3 Limited Range of EVs

The range that an EV can travel on a single charge is often lower than that of a conventional vehicle with a full tank of petrol or diesel (Schneidereit et al., 2015). In India, where long-distance travel between cities or across diverse terrains is common, limited range creates practical concerns for users. Additionally, factors like battery efficiency and energy consumption rates in different driving conditions (such as high temperatures, heavy traffic, or hilly areas) further restrict the vehicle's range (Martinez, 2024). Improving energy efficiency and battery performance is crucial to overcoming this technical limitation.

3.2.4 Environment Impact of Battery Production and Disposal

Electric vehicles typically do not emit pollutants. Furthermore the production and disposal of lithium-ion batteries, which are essential for electric vehicles, pose significant environmental challenges (McManus,2012). The mining of raw materials such as lithium, cobalt, and nickel has adverse environmental effects, including habitat destruction, water pollution, and high carbon emissions (Kuchhal & Sharma,2019). Additionally, the lack of efficient battery recycling technologies exacerbates the environmental footprint, as used batteries can lead to toxic waste and pollution if not properly managed. This technical challenge of sustainable battery production and disposal remains a significant barrier to the widespread adoption of EVs.

3.2.5 Safety

Safety concerns are a significant technical barrier to the adoption of electric vehicles (EVs). The potential for battery fires, especially from overheating lithium-ion batteries, raises fears among consumers, particularly in hot climates like India (Rezvanizaniani et al.,2014). Additionally, the lack of consistent safety standards for EV components, such as high-voltage electrical systems and battery management, adds to the risk (Bauer,2022). Safety concerns also extend to public and home charging infrastructure, which can pose electrical hazards if improperly maintained (Wang et al., 2019). Moreover, EV performance in extreme weather conditions, such as floods or high temperatures, raises questions about durability. Finally, the quiet operation of EVs increases the risk of accidents, as pedestrians may not hear them approaching. Addressing these technical safety issues is crucial for building consumer confidence in EVs.

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3.3Financial Barriers

3.3.1 High Cost

The initial purchase price of electric vehicles is significantly higher than that of traditional internal combustion engine (ICE) vehicles. This is primarily due to the high cost of lithium-ion batteries, which make up about 40% to 50% of the total cost of an EV (*Slowing U.S. EV Sales, High Manufacturing Costs Will Drive Search for Efficiency*, 2024). Although EVs have lower running costs in terms of fuel and maintenance, the high upfront price is a major deterrent for price-sensitive consumers in India, especially in lower-income and rural areas.

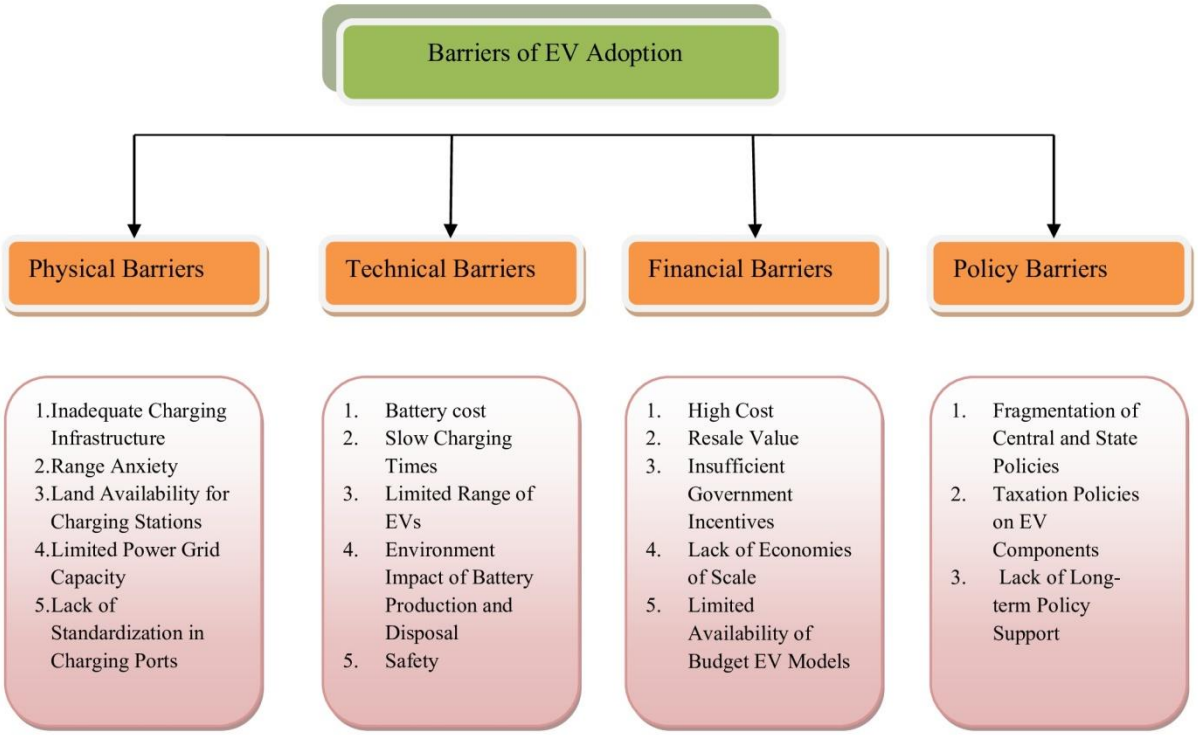

Fig.2. Barriers of EV adoption

3.3.2 Resale Value

The absence of a robust secondary market for electric vehicles contributes to concerns over the resale value of EVs. Consumers hesitate to invest in a high-cost vehicle if they are uncertain about its resale potential (Naeem,2023). This uncertainty stems from factors such as battery degradation over time, lack of established standards for used EVs, and the evolving nature of EV technology. The fear of a steep depreciation in value further limits consumers' willingness to adopt EVs (Brückmann et al.,2021).

3.3.3 Insufficient Government Incentives

The implementation of policy is an essential element in any economy to achieve its objectives (Pateer et al.,2024; Muradi & Sandhu,2023). While the Indian government has introduced various subsidies and incentives under schemes like FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) **(**Dhankhar et al., 2024a) the financial support is often not enough to offset the high initial cost of purchasing an EV. Additionally, the benefits from these schemes may not be accessible to all consumers due to eligibility criteria, delays in disbursement, or a lack of awareness about the available incentives (Aijaz,2022). Therefore, without substantial and sustained financial incentives, potential EV buyers may be deterred by the high upfront costs.

3.3.4 Lack of Economics of Scale

The relatively low production volume of EVs in India prevents manufacturers from achieving economies of scale, which would drive down costs. Unlike traditional ICE vehicles, which are produced in massive numbers and benefit from established supply chains, the EV market in India is still in its early stages. The limited production capacity results in higher per-unit costs, which are passed on to consumers. Until demand and production increase significantly, this barrier will continue to keep EV prices high.

3.3.5 Limited Availability of Budget EV Models

Most electric vehicles available in India are positioned in the mid to high-end segments, with few budget options for cost-conscious consumers. Entry-level EVs are scarce, and those that are available often lack the features, range, and performance that buyers expect. The lack of affordable EV models prevents broader adoption, especially in the lower-middle and middle-income groups who make up a significant portion of India's vehicle buyers.

3.4 Policy Barriers

3.4.1 Fragmentation of Central and State Policies

One of the major policy barriers in India is the inconsistency and lack of coordination between central and state governments. While the central government has introduced overarching policies like the FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme, the adoption and implementation of EV policies vary greatly across different states. Some states have progressive EV policies with subsidies and tax incentives, while others lag behind. This inconsistency leads to a lack of uniformity in regulations, confusing potential buyers and manufacturers about the benefits they might receive depending on their location.

3.4.2Taxation Policies on EV Components

India's import duties and taxation policies on key EV components, such as lithium-ion batteries and electric motors, are another significant policy barrier. High taxes on these imported components drive up the costs of manufacturing EVs in India. Although the government has reduced the Goods and Services Tax (GST) on EVs to 5%, import duties on critical components remain high, making it difficult for local manufacturers to compete with traditional internal combustion engine (ICE) vehicles (Ministry of Heavy Industries). Additionally, the lack of policies to encourage local manufacturing of EV components further exacerbates this issue.

3.4.3Lack of Long-term Policy Support

The lack of clarity and long-term vision regarding EV policies creates uncertainty for both consumers and manufacturers. Government incentives and subsidies, such as those provided under the FAME scheme, are often time-bound or dependent on annual budgets. This unpredictability discourages long-term investments in the EV market, as stakeholders are unsure whether the financial support will continue in the future. Manufacturers may hesitate to scale up production, and consumers may delay purchasing decisions, fearing that the incentives could be withdrawn.

4. Opportunities for Growth and Development of Electric Vehicles in India

India presents a significant opportunity for the growth and development of EVs, driven by environmental concerns, policy support, and market potential. The shift to electric mobility has become increasingly critical as the nation struggles with severe air pollution and a high reliance on fossil fuels.

4.1 Government Initiatives and Policies

The Indian government has introduced various policies to encourage EV adoption, such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme and the Production-Linked Incentive (PLI) scheme for advanced battery technologies (Dhankhar et al., 2024a). These incentives aim to reduce the cost of EVs, boost infrastructure development, and stimulate domestic manufacturing of EV components. Additionally, state governments are offering subsidies, tax exemptions, and establishing dedicated EV policies to promote the growth of the sector. These initiatives help create a favourable environment for consumers and manufacturers alike, fostering the rapid expansion of electric mobility.

4.2 Technological Advancements

Technological innovations in battery technology and charging infrastructure are opening new opportunities for EVs. Improvements in lithium-ion battery efficiency and the development of next-generation solid-state batteries are expected to lower costs and increase driving range, addressing two major barriers to adoption **(**Scrosati, 2015). The emergence of fast-charging networks and solar-powered charging stations further enhances the viability of EVs, especially in urban areas.

These advancements can accelerate the development of more affordable and long-range EVs, attracting a broader consumer base.

4.3 Market Potential

India's growing middle class, rising awareness of environmental issues, and increasing fuel prices are driving the demand for cleaner, cost-effective transportation alternatives. Major automobile manufacturers are investing heavily in EV production, recognizing the untapped potential in both urban and rural markets. As the EV ecosystem expands, opportunities for new business models, such as battery swapping, EV financing, and shared electric mobility, will emerge, creating a thriving market.

4.4 Infrastructure Development

The expansion of public charging infrastructure is critical to the growth of the EV market. Currently, there are only 12,146 charging stations nationwide, which is insufficient to meet the needs of the rapidly growing EV population. However, with government and private sector collaboration, there is a significant opportunity to develop a more widespread charging network, especially in semi-urban and rural areas. Building smart grids and integrating renewable energy sources into charging infrastructure will further enhance the sustainability of electric mobility.

4.5 Export Potential

As global demand for EVs increases, India has the potential to become a hub for EV manufacturing and exports. With its competitive labor costs and growing expertise in automotive technology, India can position itself as a leader in the production of affordable EVs and battery components for international markets.

5. Conclusion

The adoption of EVs in India presents both significant opportunities and challenges. India's transportation sector, which heavily relies on fossil fuels, contributes substantially to air pollution and greenhouse gas emissions. In response, the government has launched various initiatives, including the National Electric Mobility Mission Plan (NEMMP) and the FAME schemes, to promote the use of EVs as part of a broader push for sustainable transportation. However, despite these efforts, EV adoption in India remains at an early stage, with EVs making up less than 1% of the total vehicle market. The slow adoption is primarily due to several barriers, including the high upfront cost of EVs, inadequate charging infrastructure, range anxiety, and the absence of standardized charging systems.

The comparison between EVs and traditional internal combustion engine (ICE) vehicles shows clear advantages for EVs in terms of environmental impact and long-term cost savings. EVs have zero tailpipe emissions and offer lower maintenance costs, making them more environmentally friendly and economically viable in the long run. However, ICE vehicles still dominate the market due to their lower initial purchase price, greater range, and well-established refuelling infrastructure.

Barriers to EV adoption are categorized into physical, technical, financial, and policy-related challenges. Physical barriers, such as limited charging infrastructure and range anxiety, are critical issues in India, particularly in rural and semi-urban areas. Technical challenges include the high cost of lithium-ion batteries, slow charging times, and the environmental impact of battery production and disposal. Financial barriers, such as the high cost of EVs, insufficient government incentives, and the lack of affordable models, further hinder adoption. Policy barriers, including inconsistent coordination between central and state governments, high taxation on EV components, and unclear long-term policy support, also contribute to the slow market penetration of EVs.

Despite these challenges, India holds immense potential for the growth of EVs, driven by government support, technological advancements, and increasing market demand. Improvements in battery technology, the expansion of charging infrastructure, and the rise of new business models like battery swapping and EV financing are likely to accelerate EV adoption. With continued focus on overcoming these barriers, India is well-positioned to become a global leader in electric mobility, contributing significantly to global climate goals and reducing its carbon footprint**.**

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