



Original Article

Electric Vehicles: Opportunities and Challenges for Global Adoption

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Manuscript ID:

IBMIIRJ -2025-020308

Submitted: 02 Feb 2025

Revised: 25 Feb 2025

Accepted: 22 Mar 2025

Published: 31 Mar 2025

ISSN: 3065-7857

Volume-2

Issue-3

Pp. 36-40

March 2025

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Quick Response Code:



Web: <https://ibrj.us>



DOI: 10.5281/zenodo.15421999

DOI Link:

<https://doi.org/10.5281/zenodo.15421999>



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Abstract

The electric vehicle (EV) industry considered as a pivot for sustainable transport solution is going through a transformational phase. Over the last two decades, among growing environmental concerns and technological demands, EVs have transitioned from being niche to mainstream transport mode. While EV adoption is rising globally, it varies from region to region as well as across vehicle segments and has to overcome its share of challenges. This paper looks at the recent trends in global EV adoption, various opportunities available for different stakeholders and challenges faced by EV industry globally. The study is exploratory in nature and based on industry databases and consumer experiences. From the study, it is evident that EV adoption in emerging economies is lagging that in developed market and provides good potential for automakers. Heavy EVs are still untapped segment worldwide except for public bus transport. Electrification of two-three wheelers in emerging economies can be achieved quickly with government policy support. Purchase incentives and availability of charging infrastructure are key aspects to accelerate EV adoption. Innovative battery technology is critical to the growth and sustainability of EV industry. EV adoption worldwide is likely to grow, at the same time full electrification of vehicles is distant or improbable as not all automakers views EVs as the only means of sustainable transport solution.

Keywords: Electric vehicle, Battery, Charging, Environment, Sustainable Development

Introduction

Today sustainable development has become one of the indispensable agendas discussed globally. The need for sustainable development is now acknowledged by almost everyone be it academia, governments, industries, as well as consumers. Industrial growth, urbanization, and ever increasing consumption have put strain on environment. Over the past three decades, addressing environmental challenges such as depletion of natural resources, pollution, climate change, waste management etc. have become an important aspect of industrial development. 'The 2030 Agenda for Sustainable Development' adopted by all United Nations members highlight responsible production, clean energy, climate action and sustainable transport as some of the global Sustainable Development Goals (SDG).

Today transport modes are primarily based on the usage of fossil fuels, making transportation one of the largest sources of air pollution. Among the various agents responsible for adverse climate change, transportation alone is contributing about one quarter of all greenhouse gas emissions. Growing concerns for environmental issues, climate change as well as to reduce dependency on fossil fuels vehicles powered by electricity are emerging as a promising transportation solution. An electric vehicle (EV) is a vehicle whose propulsion is powered fully or mostly by electricity. EVs offer cleaner and more efficient alternatives to traditional internal combustion engine vehicles.

Electric vehicles have a rich history, dating back to the early 19th century. Usage of electricity during second industrial revolution gave rise to mass utilization of DC and AC electric motors. Commercial EVs appeared around 1890s. During this time use of electricity for motor vehicle propulsion was preferred as it provided level of quietness, ease of operation and no emissions that could not be achieved by that times gasoline engine vehicles. During the 20th century, use of private electric vehicles compared to internal combustion engine vehicles remained relatively very low. Battery technologies were not yet advanced and provided limited storage for energy resulting in shorter range.

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How to cite this article:

Bendre, A. (2025). Electric Vehicles: Opportunities and Challenges for Global Adoption. *InSight Bulletin: A Multidisciplinary Interlink International Research Journal*, 2(3), 36–40. <https://doi.org/10.5281/zenodo.15421999>

Along with this, the higher cost and lower top speed constrained the adoption of private electric vehicles during this time. On the other hand, commercial EVs have been in operation mainly for loading and freight equipment. They have also been widely in use for Public transport - primarily rail vehicles. Nevertheless, the electric vehicle technology continued to evolve throughout the 20th century. Towards the end of 20th century, hybrid electric vehicles were introduced. These vehicles used electric motors as a secondary source of propulsion and gained popularity in the late 1990s. Another variation namely plug-in hybrid EVs were introduced which used electric motors as the primary source of propulsion in addition to internal combustion engine. These were mainly passenger cars but could undergo mass production only after late 2000s. Battery electric cars, a pure EV form, became practical option for the consumer market only towards end of 2010s.

Start of the 21st century saw revival of the private electric vehicles. Sustainable development agendas like climate change and reducing dependency on fossil fuels have brought changes to various government policies and regulations. Compliance to these changes as well as government incentives for electric vehicles along with advancements in batteries and electric vehicle technologies have given rise to increased interest in electric vehicles.

Toyota Prius, which is considered as world's first mass-produced hybrid electric vehicle, was first introduced in Japan in 1997. The Prius was released worldwide in 2000 and it sparked the revival of private EVs. The other event considered to have reshaped electric vehicles was the announcement by Tesla Motors in 2006 that it would produce electric car that could travel 200 miles on a single charge. Tesla's announcement and subsequent success (it released the announced vehicle in 2008) prompted other big automakers to work on their own electric vehicles.

Over the past two decades electric vehicles industry has undergone significant transition. EVs are becoming a mainstream option rather than remaining a niche product. However, adoption of EVs is not without hurdles. Despite huge investments by automakers, EV sales are weaker than expected. If this situation continues, it may lead to significant layoffs and factory closures. Ford recently announced that it would cut nearly 4,000 jobs in Europe by 2027 to reduce costs as EVs demand is below expectation. Similarly, Volkswagen plans to close at least three factories in Germany and cut several jobs due to lower EV performance. This reflects challenges in demand projection and scaling production. China, one of the primary market for EV has seen significant price wars, which even the industry leader Tesla had to face. At the same time, not all automakers are yet fully convinced about the mass adoption of EVs. Toyota, who pioneered hybrid electric vehicles does not believe in all-electric future for vehicles and has pressed for mixed portfolio. This uncertainty further complicates the global outlook.

This highlights the need for a review of status of global EV industry. The objective of this paper is to examine the technological, economic, regulatory, and social aspects of EV adoption, focusing on both the opportunities and the challenges for global implementation.

Global Trends in Electric Vehicle Adoption

This section provides a summarized review of global trends in adoption of electric vehicles based on yearly reports from the International Energy Agency (IEA). Over the last decade, electric vehicles have received significant attention from both automakers as well as consumers. The need for sustainable and eco-friendly transportation has galvanized the automobile industry towards EV research and production resulting in increased popularity of EVs. At the same time, there have been concerns about the EV industry's growth rate due to numerous hurdles such as high inflation, fluctuating raw material prices, reducing margins and phasing out of initial purchase incentives in some countries. Despite these hurdles, global sales data of EVs over the past few years (post Covid-19 period) remain strong, which suggest a good future for EV adoption.

Trends in Electric Cars: Electric cars are gradually becoming a mainstream vehicle choice in an increasing number of countries. Their sales has witnessed robust growth in key markets such as China, Europe and United States, which is further increased by EV adoption by emerging economies.

By end of 2023, the global EV market had reached over 40 million cars on the road with nearly 32% yearly growth compared to previous year. It is anticipated that by 2025, the share of new EV cars could nearly be one in two in China, one in four in Europe, and one in eight in United States. In 2023, these three regions accounted for around 65% of total car sales worldwide. Chinese carmakers alone produced more than half of all electric cars sold worldwide in 2023.

Norway leads the battery-electric vehicle sales. Since 2023, battery EVs accounts for nearly 90 % of all new vehicles sold in Norway. It is about to become the first country to phase out sales of new petrol and diesel (fossil fuels) vehicles by 2025.

While electric car sales in emerging economies are lower compared to those in three big markets (China, Europe and U.S.), growth picked up in 2023 in countries such as Thailand and Vietnam. EV growth in emerging economies is driven by supporting policy measures, such as incentives for domestic manufacturing of EVs and their batteries as well as purchase subsidies for consumers.

During 2023, nearly 2% of all cars sold in India were EVs. Though all car sales witnessed a growth rate of under 10%, electric car registrations grew by nearly 70% year-on-year basis to 80 000. The growing Indian demand for EVs during the past few years can be attributed to various positive measures by government like purchase incentives under the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme, supply-side incentives under the Production Linked Incentive (PLI) scheme, tax benefits and the Go Electric campaign.

Trends in Electric Two/Three Wheeler Vehicles: Two- and three-wheeler (2/3W) segment represents the most electrified road transport mode globally, with nearly 65 million electric 2/3Ws on the road today (about 8% of total 2/3Ws). In 2023, the share of new electric 2/3Ws was just about 13% of total global 2/3W sales. India, China and ASEAN countries are the biggest 2/3W markets accounting for nearly 95% of worldwide electric 2/3W sales. In 2023, China sold the most electric 2/3Ws (30% of total 2/3Ws), followed by India (8%) and ASEAN countries (3%).

The global sales of electric two-wheelers (2Ws) has fallen since 2022 because of supply chain constraints linked to China's Covid-19 related restrictions. This global sales drop was primarily driven by China, which contributes to majority (nearly 78%) of global electric 2W sales. At the same time, sales in expanding Indian market and ASEAN countries have shown steady growth.

India accounts for the majority stock of 2Ws and 3Ws worldwide. In 2024, India became largest 2W market in the world surpassing China. While India is the second largest electric 2Ws market globally, it overtook China in 2023 to become the largest market for electric 3Ws. Therefore, India's EV adoption in the 2/3W segment is prime opportunity for decarbonizing road transportation. India is making steady progress with nearly 25% of the country's 3Ws being electric. Today, emerging and developing economies account for almost 90% of the global traditional 2/3Ws fleet. Therefore, it is important that these economies achieve full electrification of 2/3Ws over the next few years, which is possible with the help of policy measures such as tax benefits, manufacturing incentives and purchase subsidies.

Trends in Heavy Duty Electric Vehicles: Electric buses are predominant form of heavy electric vehicle other being electric trucks. City buses with somewhat regular driving patterns and lower daily distances to be travelled have strong potential for electrification and are central to growth in electric bus sales.

Electric trucks usage is gaining momentum. In 2023, for the first time, total sales of electric trucks crossed that of electric buses. China, which has the largest market for electric trucks accounted for 70% of global sales in 2023. Europe and U.S. saw nearly three times increase in annual sale of electric trucks in 2023 but that remains less than 2% of total truck sales. Stricter policies and emission norms in these regions are expected to drive electric truck sales.

Manufacturers outside China, Europe and North America have not responded to the heavy duty electric vehicle actively resulting in slower growth and fewer supportive policies. In India, government has planned to collaborate with private sector entities for large scale freight electrification through a platform named as Electric Freight Accelerator for Sustainable Transport (e-FAST).

Trends in Electric Vehicle Charging Infrastructure: As of now home charging is the most convenient and widely used method for charging light EVs. Users with access to parking area and charging fitment can charge their EVs whenever needed. Home charging is also economical owing to lower electricity prices for residential supply.

The accessibility of home charging option may vary based on urban, suburban and rural locations, as well as users income bracket. In dense cities, where parking space is limited and shared, individual home charging may not be possible and users have to depend on public charging. European Union have proposed changes to building regulations that makes provision of chargers mandatory and will help increasing access over time. United Kingdom, the first country to release smart charge point regulations, has over 90% access to home charging. As of 2023, 55% of Indian consumers reported accessibility of home charging option.

Many countries are shifting focus to charging infrastructure development and deployment of public chargers. Availability of public charging facility and the interoperability of its infrastructure are important aspects for large scale adoption of EVs. Heavy electric vehicles need fast charging option with higher wattage. Worldwide efforts are being made for standardization of megawatt-scale chargers in order to achieve maximum interoperability for heavy electric vehicles.

Battery swapping technology, an alternative to regular charging, used mostly in China, would save charging time, prolong battery life due to controlled charging, and reduce the electricity grid load by distributing power demand over a longer period.

Another charging infrastructure innovation that is still in nascent stage is Electric road systems (ERS) which will allow vehicles to charge while they are driving. In 2023, Sweden became the first country to promise to build electrified road, which is expected to open to the public by 2025.

Trends in Electric Vehicles Batteries: The demand for batteries will keep increasing with growing EV sales. The increased EV sales contributed to nearly 95% of the growth in global EV battery demand, while about 5% growth was a result of larger average battery size as are required by electric SUVs.

Today, the domestic battery productions in China, Europe and the U.S. can cater to global EV battery demand but manufacturing in Europe and the U.S. is more expensive than in China. China is the world's largest EV battery exporter and exports nearly 12% of its production, which even Europe and U.S. imports.

Growing EV battery requirements has pushed up demand for critical raw materials like cobalt, lithium and nickel. The most used battery chemistry is Lithium-iron-phosphate (LFP) which catered to nearly 40% global EV demand in 2023. LFP battery production is higher in China and nearly two in three EVs sold in China used it. EVs sold in Europe and the U.S. primarily used nickel batteries while share of LFP was less than 10%. In 2023, leading battery manufacturers announced expansion plans for sodium-ion batteries, which could lower battery prices up to 20%.

Opportunities for Global Electric Vehicle Adoption

Adoption of electric vehicles presents numerous opportunities along with sustainable transport to consumers, industries as well as society. This section summarises the same.

- **Environmental Benefits of EVs**
 - Reduction of Greenhouse Gas Emissions: EVs contribute significantly to reducing carbon emissions, particularly if they are charged with renewable energy sources.
 - Reduction of Air Pollution: EVs produce no tailpipe emissions, eliminating smoke, haze and improving air quality particularly in urban areas that contribute positively to public health.

- **Reduction of Noise Pollution:** EVs mostly operate silently or very less sound and thus eliminates the noise pollution specifically in high population density public areas.
- **Cost Reduction and Economic Growth**
- **Lower Operating Costs:** EVs are typically cheaper to operate than conventional vehicles due to lower fuel and maintenance costs.
- **Job Creation:** The transition to electric vehicles has the potential to create jobs in manufacturing, installation, and maintenance of EVs and related infrastructure (e.g., charging stations).
- **Energy Security:** EVs will reduce dependence on fossil fuels as well as contribute to energy diversification by integrating renewable energy sources like solar and wind.
- **Government Incentives and Policies**
- **Subsidies and Tax Breaks:** Many countries offer incentives, rebates, and subsidies to encourage consumers to purchase EVs making them affordable. Automakers too are offered such benefits by government to encourage EV manufacturing and sale.
- **Regulations and Emission Standards:** Increasingly strict emission regulations are pushing automakers to develop and adopt EV technologies to meet sustainability goals.
- **EV Mandates:** Several countries and cities have set ambitious targets for the adoption of electric vehicles, creating a clear policy path for the transition to a low-carbon transportation future.
- **Technological Advancements and Infrastructure Development**
- **Battery Innovations:** Ongoing improvements in battery capacity, energy density, and charging speed will improve range and make EVs more practical for consumers. Newer battery chemistries would reduce battery cost resulting in more affordable EVs. Battery swapping technology would reduce waiting time, increase battery life resulting in lower maintenance cost.
- **Charging Infrastructure:** Expanding the network of fast chargers and integrating charging stations into public infrastructure, such as highways and urban centers, will make EVs more convenient for drivers and equally accessible to all. Innovation such as Electric road systems would reduce operating costs and facilitate faster adoption of EVs.
- **Future Opportunities**
- **Emerging Economies:** Developing regions such as Africa, India and Southeast Asia have great potential for mass EV usage. This potential can be tapped significantly because automakers can develop affordable, entry-level EV models for these emerging economies.
- **Electric Trucks:** This remains least adopted vehicle type in the regions other than China and needs to be tapped with the help of policy and incentives.
- **Used Electric Vehicles:** Used electric vehicles will be easily available for resale once the EV markets mature. The second hand electric car prices are decreasing significantly and are becoming competitive with those of traditional combustion vehicles.
- **Battery Recycling:** The security and sustainability of EV supply chain demands recycling and reuse of batteries. EV end-of-life markets therefore offer good opportunities, which are being explored by many technology developers.

Challenges for Global Electric Vehicle Adoption

Adoption of electric vehicles presents numerous challenges to various stakeholders be it consumers, industries or governments. This section summarises the same.

- **High Initial Purchase Cost**
- **Price Parity:** EVs, particularly new models with longer ranges, can be significantly more expensive than traditional vehicles. Although operational costs are lower, the upfront cost remains a significant barrier particularly for middle and lower income consumers. Governments in some developing economies may not have sufficient funding available for giving incentives.
- **Battery Cost:** The high cost of lithium-ion batteries remains one of the primary factors driving up the price of EVs.
- **Limited Charging Infrastructure**
- **Availability of Charging Stations:** One of the main hurdles to mass EV adoption is the absence of adequate charging infrastructure, mostly in rural areas as well as in developing nations. Some developing countries also face issues of grid reliability hindering their progress for EV adoption. As more heavy electric vehicles hit the road, they will need dedicated and standardized charging stations.
- **Charging Time:** While charging infrastructure is improving, the time required to charge an EV is still longer than refueling a conventional vehicle, which can be inconvenient for users on long trips.
- **Battery Limitations**
- **Range Anxiety:** The limited range of many EVs compared to traditional vehicles creates concerns about being stranded without access to charging stations.
- **Battery Lifespan and Recycling:** While EV batteries are improving, concerns remain about their lifespan, the availability of raw materials for production, and the environmental impact of disposing of and recycling used batteries.
- **Market Barriers and Consumer Perception**
- **Lack of Awareness and Understanding:** Many consumers still do not have appropriate knowledge about EVs and their benefits or have misconceptions about their cost, range and reliability.

- **Cultural Resistance:** In some regions, there may be resistance to adopting new technologies, especially if consumers are accustomed to traditional gasoline-powered vehicles. Markets dominated by heavy vehicles and SUVs are resistant to EV adoption.
- **Supply Chain and Raw Material Constraints**
- **Battery Materials:** The rapid increase in demand for EVs is putting pressure on the supply chains for raw materials which are essential for battery production namely cobalt, graphite, lithium, and nickel.
- **Global Supply Chain Disruptions:** The Covid-19 pandemic, geopolitical tensions and environmental issues concerning mining operations have emphasized the vulnerabilities of the global supply chain for necessary materials needed in EV production.

Conclusion

Adoption of Electric Vehicles as an alternative to traditional combustion engine vehicle is a step towards sustainable development. Use of EVs provide multiple benefits like reduction of greenhouse emissions, reduction of air and noise pollution, reduction in fossil fuel usage all of which translates to cleaner environment. Their higher initial cost is a major hurdle in EV adoption. Underdeveloped charging infrastructure, constrained battery capacities, longer charging time put limitations on s EV usage for long journey. To overcome the challenges in widespread adoption of EVs, governments need to incentivize both consumers and manufacturers, invest in deployment of easy accessible charging stations and support research on EV and battery technology.

Further detail research can be undertaken to understand status of EV adoption in India and to explore specific challenges faced by Indian EV industry.

Acknowledgement

I express my sincere gratitude to everyone who supported me throughout the course of this research work. My deepest gratitude to the principal Dr. Kishor Desarda and Dr. Vinayak Pawar and MES Garware College of Commerce, Pune for their instrumental support in the completion of this research.

I am indebted to the members of research committee, Dr. Tanuja Devi and Dr. Nitin Ade and Organizing Committee members for their constructive feedback and thoughtful suggestions throughout this study.

I express gratitude to my colleagues and friends who provided a supportive academic environment. Their encouragement was indispensable during the challenging phases of this research.

I am deeply thankful to my family for their support, understanding and encouragement. Their belief in my abilities sustained me through the high & lows of this research.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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