

Redefining EV Diffusion Strategies in India: Insights from a Multi-Country Socioeconomic Analysis

A. Babu^{1*}, Biplab Sarkar¹

¹ PES University, 100 Feet Ring Road, BSK III Stage, Bangalore, 560085, India

* Corresponding author's e-mail: arjunbabu83@gmail.com

ABSTRACT

This research investigates the nexus between socioeconomic indicators and the diffusion of electric vehicles (EVs), with a specific focus on India's transition to electric mobility amidst its distinct challenges and opportunities as a developing nation. Utilizing the Rogers framework of diffusion of innovation, the study examines fifteen socioeconomic indicators across 36 countries to discern their influence on EV diffusion. The findings underscore the inadequacy of replicating diffusion models from developed economies for India, advocating instead for tailored strategies aligned with its unique socioeconomic context. Drawing insights from China's successful EV market, characterized by dedicated manufacturing hubs and forward-looking policies, the study recommends a nuanced approach addressing affordability, infrastructure, and incentives to ensure a seamless transition. However, the research acknowledges limitations due to the examination's narrow scope, prompting future investigations to expand the range of indicators and countries considered for a more comprehensive understanding. Ultimately, this study contributes practical recommendations for policymakers and stakeholders, emphasizing the importance of aligning EV transition strategies with India's socioeconomic realities to foster a sustainable and economically viable transportation landscape.

Keywords: GDP per capita, electric vehicles, barriers for EV diffusion, diffusion of innovation.

INTRODUCTION

The rise of fossil fuels marked a transformative phase in industrialization, serving as a primary energy source and catalyzing unprecedented economic growth and development (Black, 2020). However, this advancement came at the cost of rapidly increasing greenhouse gas emissions, culminating in the phenomenon of global warming. The Intergovernmental Panel on Climate Change (IPCC) special report anticipates a 1.5 °C increase in Earth's temperature by the mid 21st century, compared to the preindustrial era, attributing this trend to the rapid surge in greenhouse gas emissions (IPCC et al., 2018). According to 2016 data, a substantial 73.2% of the CO₂ discharges result from energy generation processes, with transportation contributing 16.2%. Further analysis reveals that road transportation is responsible for

a significant portion, comprising 73.4% with relation to the total transportation-related emissions (Ritchie et al., 2020). In response to escalating greenhouse gas levels leading to severe weather events, changing weather patterns, disruptions in the food supply chain, and increased wildfires, the market for EVs developed in the late twentieth century (Wu et al., 2019). While several research on the diffusion of EVs have been undertaken in recent years, the most of them have focused on industrialized nations (Ian Palmer, 2021; Larson et al., 2014a; Yang et al., 2023). Furthermore, past research on EV adoption indicates that EV diffusion is affected by a variety of socioeconomic indicators such as GDP per capita, urbanization, renewable energy share, gasoline price, and so on (Briseño et al., 2021; Liao et al., 2017; Ruoso and Ribeiro, 2022; Sierzchula et al., 2014).

Well-to-wheel efficiency

The well-to-wheel efficiency of EVs is pivotal for developing economies facing the dual challenge of economic growth and environmental responsibility. Electric vehicles, powered by renewable sources, exhibit high efficiency, mitigating greenhouse gas emissions and reducing dependence on imported fossil fuels. This not only curtails environmental impact but also fosters energy independence, contributing to long-term economic resilience. The strategic diffusion of EVs with a focus on well-to-wheel efficiency aligns with the imperative to balance sustainable development with industrial progress in developing nations, offering a comprehensive solution to meet energy demands while minimizing ecological consequences. The conventional vehicles well to wheel efficiency is at 13% where as well-to-wheel efficiency of EVs is 21%. In the Indian scenario the energy from renewable sources is approximately at 25% with that the well-to-wheel efficiency of EVs results into 31% (MIT EVT, 2009; MNRE, 2023).

India’s mission for electric vehicles

EVs began almost 190 years ago with Scottish inventor Robert Anderson’s non-rechargeable primary cells in 1832. In India, the EV journey commenced in 1996 with the debut of the three-wheeler “VIKRAM SAFA” by Scooter India Pvt Ltd (E-Trio, 2022). India is a founding member of the Clean energy Ministerial (CEM) established in 2017. It is a unique collaboration of the world’s leading economies aimed at expediting the worldwide transition to renewable energy.

By 2030, CEM wants EV sales to account for 30 per cent of total sales, India has taken the target of 30% EV diffusion by 2030 (Ministerial, 2017; Alyamani and Pappelis, 2024; Saw and Kedia, 2023). Figure 2 illustrates India’s EV diffusion trend, commencing from 2017–18, while Figure 3 provides a comparative analysis of India with other nations. India’s EV diffusion has been sluggish since beginning. To gain the benefits of EVs and to maintain the pace with sustainability goals, India must accelerate its growth in this journey.

Importance of socioeconomic indicators for EV diffusion

Socioeconomic indicators are essential for comprehending a nation’s social and economic progress. Many articles have utilized socioeconomic indicators, such as Ribeiro and Ruoso 2022, which used socioeconomic features to anticipate the proliferation of EVs in different nations using historical data. Briseño et al. (2021) used socio-economic indicators to establish the causal relationship between diffusion of EVs and macroeconomic indicators among different states of Mexico. These socio-economic indicators not only shed light on a country’s social and economic well-being but also play a pivotal role in predicting the diffusion of EVs.

Diffusion of innovation

The diffusion of innovation (DOI) theory, developed by Everett Rogers, describes how new ideas, products, or technologies spread through a social system. The theory identifies different

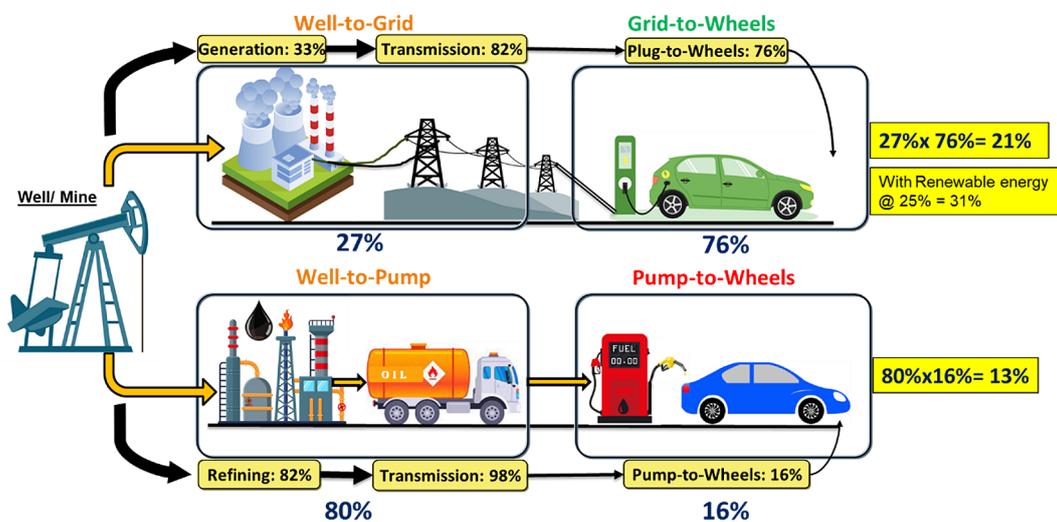


Figure 1. Well to wheel efficiency of ICE vs EVs

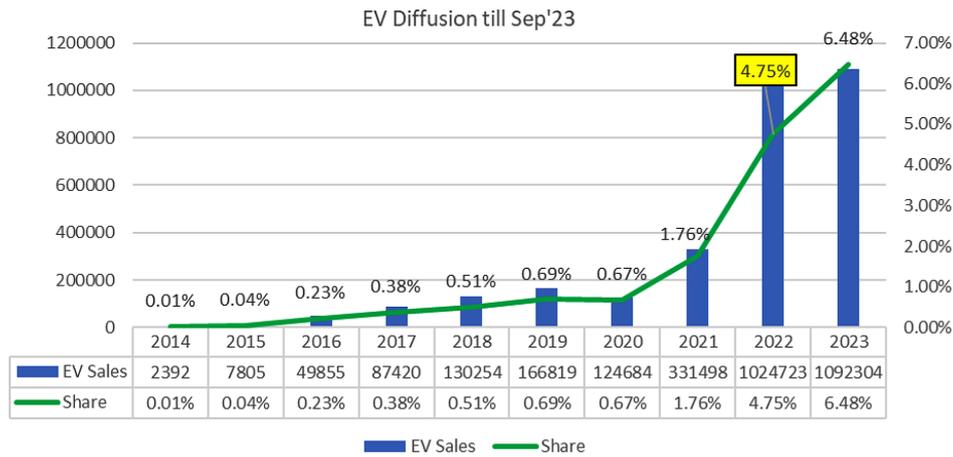


Figure 2. EV sales share trend in India, 2014–2023 (<https://parivahan.gov.in/parivahan>)

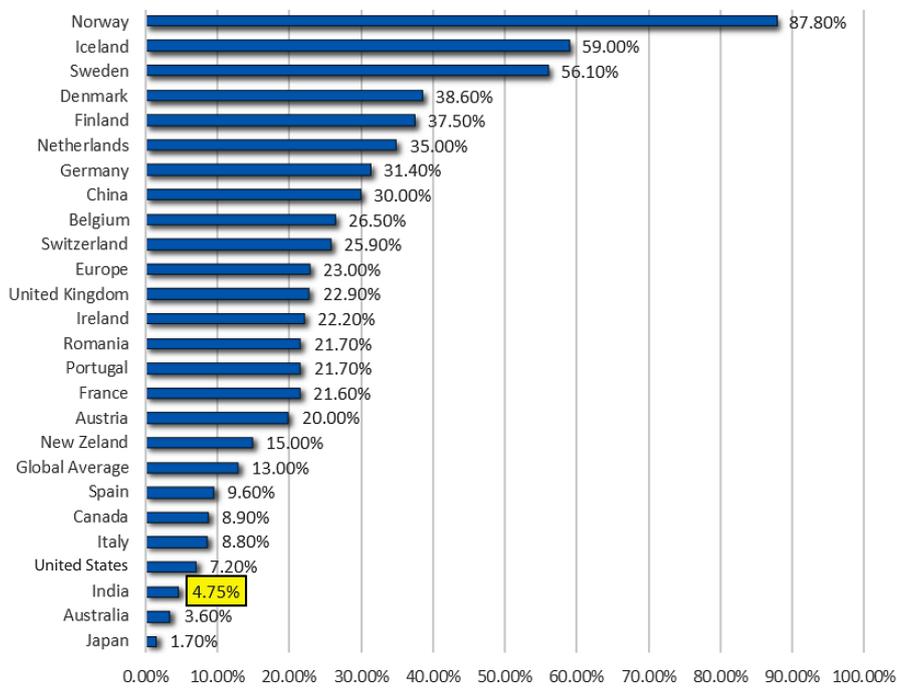


Figure 3. The share of EV sales in different countries in the year 2022

groups of people according to their willingness to adopt an innovation. The procedure for diffusion involves several stages, and individuals within a population can be classified into categories based on their adoption behavior. The Figure 4 explains the different stages in DOI (Rogers, 2001; Libai et al., 2009; Rogers et al., 2014).

Adoption categories – individuals within a population may be categorized into various groups on the basis of their adoption behavior. Rogers identified five adopter categories:

- Innovators: venturesome individuals who are eager to try new ideas.

- Early adopters: opinion leaders who adopt new ideas early but carefully.
- Early majority: individuals who embrace a novel idea or product just before the average person.
- Late majority: skeptics who accept a new concept or product after the average person.
- Laggards: traditionalists who are the last to adopt an innovation.

Research questions

- Does the socioeconomic indicators have noticeable influence on EVs diffusion?
- Should India adopt the developed countries’ model of EV diffusion?

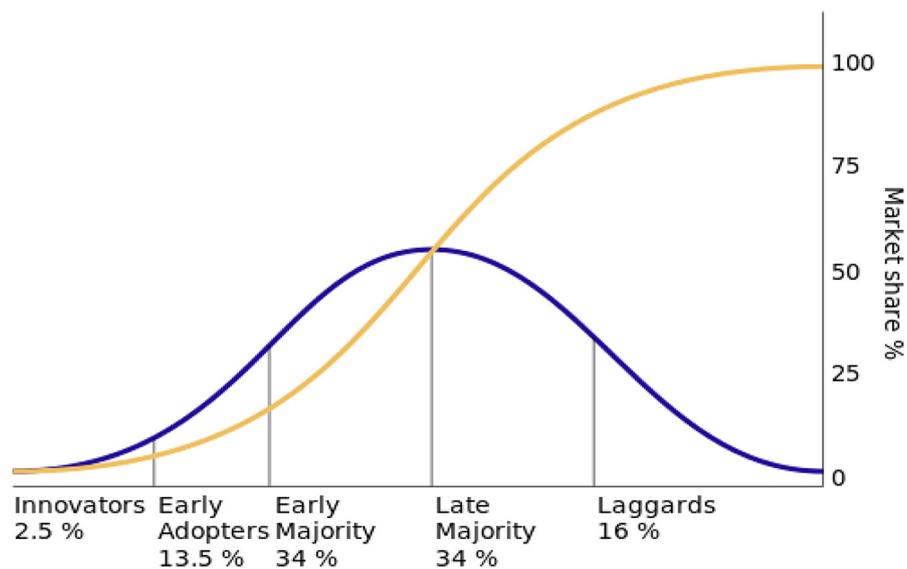


Figure 4. Diffusion of innovation graph. Source: Diffusion of innovation book by E.M Rogers (1962)

BACKGROUND

As the world strives for sustainable transportation solutions, the diffusion of EVs emerges as a critical focal point. This literature review is divided into three sections, each covering a different element of EV diffusion: the barriers to EV diffusion, the impact of socioeconomic indicators on these barriers, and a comparison of EV diffusion in developed and developing countries.

Barriers for diffusion of EVs

EVs are a transformative innovation aligning with United Nations sustainability goals, yet face barriers hindering societal diffusion. The following section outlines key barriers.

High purchase price

The higher purchase price is a highly significant barrier for diffusion of EVs, often reaching twice that of a conventional vehicle (Bhat et al., 2024; Ebrie and Kim, 2022; Ruoso and Ribeiro, 2022). The constrained availability of technology and raw materials further compounds this issue, particularly in countries with a cost-conscious market like India, Brazil, and China (Biresseoglu et al., 2018; Chhikara et al., 2021; Lévy et al., 2017). Even while many other nations believed Norway had overcome the price barrier with its abundance of incentives, Norwegian experts insisted that pricing remained the biggest obstacle to the switch to EVs. Additionally, some of experts claim that not

everyone in Norway can afford the more expensive Tesla models (Noel et al., 2020).

Driving range

The limited driving distance poses a significant concern for EV consumers, which is in the average of 150 to 250 kms (Bhat et al., 2024; Eg-bue and Long, 2012). In contrast, traditional vehicles typically achieve an 800 km range on a full tank of gasoline. Experts consider this difference a fundamental barrier to the extensive adoption of EVs (Bhat et al., 2024; Chhikara et al., 2021; Singh et al., 2020).

Battery charging time

A key impediment to mainstream EV diffusion is concerned over battery charging time. Despite advancements, existing charging systems often necessitate significant time to recharge EV batteries. Whereas the refueling a conventional vehicle would take 5 min. This difference often discourages potential EV owners and avoid mass diffusion. To address this challenge and accelerate the shift to sustainable transportation, efforts must focus on reducing charging time and improve EV access to general public (Adhikari et al., 2020; Brenna et al., 2020; S. Li et al., 2021).

Total cost of ownership

TCO for EVs varies among nations due to change in law, taxation, and special incentives such as exemptions from yearly fees, entrance

fees, and purchase limitations (Bhosale et al., 2022). Levay in 2017 notes that Norway exhibited the lowest TCO for Battery EVs compared to other European nations. While the United Kingdom, Netherlands, and France showed somewhat higher TCO for traditional vehicles. Generally, the TCO for EVs tends to be high due to the higher purchase price leading to a longer pay-back period (Bhat et al., 2024; Chhikara et al., 2021; Alyamani and Pappelis, 2024).

Limited charging infrastructure

A critical impediment to the widespread diffusion of EVs is the inadequate charging infrastructure. Insufficient EV charging infrastructure and prolonged charging times hinder successful EV adoption in many countries (Ebrie and Kim, 2022; Egbue and Long, 2012; Singh et al., 2020). Additionally, some studies argue that merely expanding the number of public charging stations may not consistently lead to a proportional increase in EV registrations (Hall and Lutsey, 2017; Mukherjee and Ryan, 2020; Ou et al., 2020).

Perception about EVs

Consumer confidence and perception of EVs as prospective options are still weak because the EV market is still in its infancy and makes up a small portion of the overall market (Berkeley et al., 2018; Lévy et al., 2017; Sierzchula et al., 2014). Financial, performance, physical, and time risks associated with EVs constitute significant barriers to their widespread adoption.

Socioeconomic indicators

Previous research on EV diffusion indicates that purchase decisions hinges on various socioeconomic factors like disposable income, education, government policies, and fuel cost (Bhat et al., 2024; Sierzchula et al., 2014). Li et al. (2017) focused on studying the influence of socioeconomic indicators on the diffusion of EVs in 14 countries between 2010 and 2015, with a special emphasis on analyzing their effects on overall demand (X. Li et al., 2017). Further to forecast potential sales volumes in Germany, Kihm and Trommer, (2014) developed a deterministic model that relies on the EVs' ownership cost. By examining the geographical and socioeconomic characteristics of adopters, policymakers and business leaders can provide valuable insights

on the initial diffusion of a technology, its geographical distribution, and the aspects driving its diffusion. This analysis can give critical information to help decision-making processes (Gielen et al., 2019).

The below socioeconomic indicators are identified for evaluating the influence on diffusion of EVs

1. GDP per capita
2. Urbanization
3. Renewable energy share
4. Fuel price
5. Human development Index (HDI)
6. Electric power consumption (kWh per capita)
7. Literacy rate
8. Access to electricity
9. Unemployment rate in %ge
10. Population density
11. CO₂ emission per capita
12. Country area in 1000 Sqkm
13. Research and development expenditure (% of GDP)
14. School enrollment, secondary (% gross)
15. Electricity price per kWh.

Each socioeconomic indicator is discussed below for its significance in society and its impact on EV diffusion.

GDP per capita

The GDP per capita (GDPPC) is a common evaluation criterion to find out whether a country is a developed, developing, or lower-income country. GDP describes the economic health of a country. Economists frequently use GDPPC to analyze the status of an economy (Well, 2007). SDG 8 includes real GDPPC yearly growth rate as a metric (Coscieme et al., 2020). Consumers may be more financially able to acquire electric automobiles in nations with higher GDPPC levels. Advanced economies may be more willing to invest in infrastructures of renewable energy and research and development. While several variables impact the diffusion of EVs, GDPPC may play a important role in creating favorable economic circumstances that encourage market growth.

Urbanization

Cities with dense populations now host more than half of the world's population. This change in urban population has modified the way we interact with one another, live, work, and travel (Ritchie and Roser, 2018).

EVs are well-suited for urban commuters with shorter travel distances. Despite concerns, urbanization offers both challenges and opportunities for EV diffusion, as cities may have the infrastructure and regulations to support EV growth, making urbanization a strong predictor of EV adoption (Pan et al., 2024).

Renewable energy share

EVs and renewable source of energy are both important components of the transition to a low-carbon economy. The usage of EVs, which may be driven by renewable energy sources, helps to minimize transportation's carbon impact. Renewable energies appear to be among the most feasible and efficient options in this respect (Dincer, 2000).

Fuel price

Fuel prices significantly influence EV adoption. Approximately 2/3rd of the total ownership cost of conventional vehicles is attributed to fuel prices. Financial savings from EV ownership become more apparent as petrol prices rise. Consumer inclination towards EVs increases when gasoline or diesel costs are high or unstable. Some nations levy a carbon tax on fossil fuels to narrow the TCO gap, making EVs a more competitive option. Rising fuel costs make consumers more likely to view EVs as a cost-effective and environmentally friendly alternative.

Human development index (HDI)

The human development index (HDI) comprehensively evaluates a nation's performance in key dimensions of human development, quantifying progress in well-being (Masduki et al., 2022). Higher HDI-ranked countries, with elevated income levels, improved infrastructure, and enhanced access to healthcare and education, exhibit greater acceptance of EVs. Despite higher costs and charging infrastructure needs, people in these nations are more inclined to adopt EVs.

Electric power consumption (kwh per capita):

The higher electricity consumption per capita syndicates higher industrial output and employment with better disposable income at an individual level (Eras et al., 2022). EVs diffusion is typically higher in nations with

greater electricity usage, as strong electrical infrastructure accommodates EV charging needs. Electricity consumption aligns with economic development levels.

Literacy rate

Literacy is often linked to education and awareness, which may lead to a good grasp among the advantages of EVs and a stronger readiness to adopt them. Literacy might also signify better access to information and services, like charging stations, facilitating EV use. However, economic status, infrastructure, and government legislation significantly influence EV diffusion.

Accessibility to electricity

The availability of electricity has a critical role on the diffusion of EVs. Limited or intermittent access to electricity poses challenges for providing sufficient EV charging infrastructure. Technological advancements, such as solar panels and battery storage, offer alternatives less reliant on the grid. The cost of electricity is a critical factor influencing EV diffusion; high power costs can make EV operation more expensive than conventional gasoline vehicles.

Unemployment rate

The link between EV diffusion and the unemployment rate is complex by a number of factors that might impact each measure. A higher unemployment rate may hinder EV adoption due to reduced disposable income.

Population density

Understanding population dynamics about socioeconomic change and sustainable development provides you with a better understanding of how the world operates (Weeks, 2020). Population density and the use of EVs are intricately correlated since different geographic areas and social groups may adopt EVs for various reasons.

CO₂ emission per capita

The diffusion of EVs and CO₂ emissions are directly linked. The higher CO₂ emission represent higher industrial activity with better GDP per capita & higher disposable income of its citizens who can afford the EVs and has the knowledge of CO₂ consequences.

Country area in 1000 km²

A country's size can influence EV diffusion. In larger nations, long-distance driving poses challenges due to range limits and sparse charging infrastructure between cities. Larger countries may have varied driving conditions and temperatures, making certain areas more suitable for EVs. Smaller nations, with densely populated urban areas and shorter travel distances, find EVs more practical for daily use.

Research and development expenditure (% of GDP)

The advancement of EVs in cost-effectiveness, performance, and widespread usage is intricately linked to Research and Development (R&D) initiatives. R&D is critical to advancing EV adoption, with a strong emphasis on ongoing development of EV batteries. Efforts concentrate on enhancing energy density, reducing costs, and extending battery lifespan, critical components of EVs. These advancements, offering increased driving range and reduced expenses, significantly boost EV appeal, promoting wider diffusion.

School enrollment

While the direct relationship between school enrollment and the diffusion of EVs may not be evident, education can significantly influence it. Education plays a crucial role in raising awareness about EV benefits and the adverse impacts of traditional transportation on the environment and economy. Particularly vital is the role of education in enhancing understanding of the infrastructure and technology needed for EVs (Melrose Pan et al., 2024).

Electricity price

The electricity price plays a critical role in EV diffusion as it's one of the main attractions due to their lower operating costs compared to traditional ICE vehicles. The TCO includes not only the initial purchase price of the vehicle but also ongoing costs such as fuel or electricity, maintenance, and repairs. Lower electricity prices contribute to a lower TCO for EVs, increasing their competitiveness with traditional vehicles and encouraging consumers to make the switch.

Diffusion of EVs in developed countries vs developing countries

Diffusion of EVs in developed countries

The diffusion of EVs in developed countries has witnessed notable growth in recent times. Governments in these nations have played a pivotal role in fostering EV adoption by implementing supportive regulations and offering a range of financial incentives to prospective buyers. These incentives, including tax breaks, rebates, and subsidies, EVs' overall cost is successfully reduced, making them more appealing to customers. Norway, for example, has the world's greatest EV diffusion rate and EVs account for greater than 86% of new automobile sales (Yang et al., 2023). The higher diffusion is due to the numerous incentives provided by governments, such as access to bus lanes, exemptions from tolls, parking fees, sales taxes, and VAT etc. (Gropp and Ohlsson, 2017; Mersky et al., 2016) (Hackbarth and Madlener, 2013; Sang and Bekhet, 2015; Zhang et al., 2011). As shown in the below Table 1, few of the developed countries have declared that they would be phasing out the ICEs before 2050 (Aayog et al., 2022).

Overview of incentives in the developed countries

In developed countries, a range of incentives promotes EV diffusion, emphasizing sustainable transportation alternatives. Financial incentives, like tax credits and rebates, reduce upfront EV costs. Governments support home-charging infrastructure development and offer perks such as public bus lane access, reserved parking, and toll exemptions for EV owners. To alleviate range anxiety, comprehensive charging infrastructure networks are being established. These incentives collectively create an environment conducive to widespread EV adoption in developed nations, ensuring a more sustainable and environmental friendly urban mobility future (Münzel et al., 2019; Ryan Alyamani and Pappelis, 2024). Figure 5 categorizes incentives under monetary and non-monetary categories. The Figure 6 shows the various support incentives given by the majority of developed countries

Diffusion of EVs in developing countries

EV diffusion in emerging countries lags behind developed nations due to elements such as higher upfront costs, range anxiety, poor charging

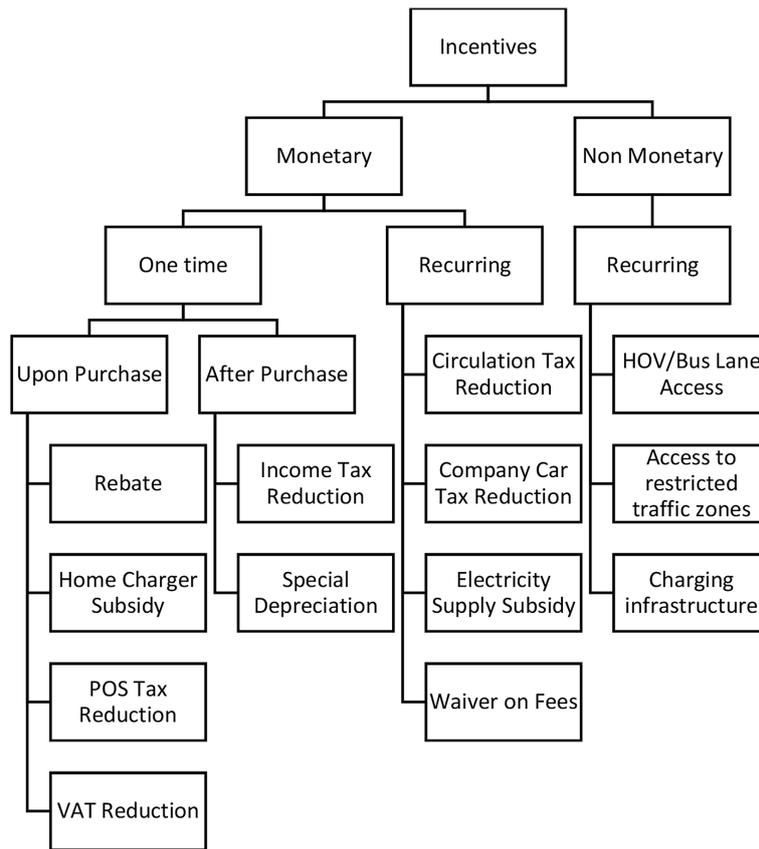


Figure 5. EV incentives classification (Münzel et al., 2019)

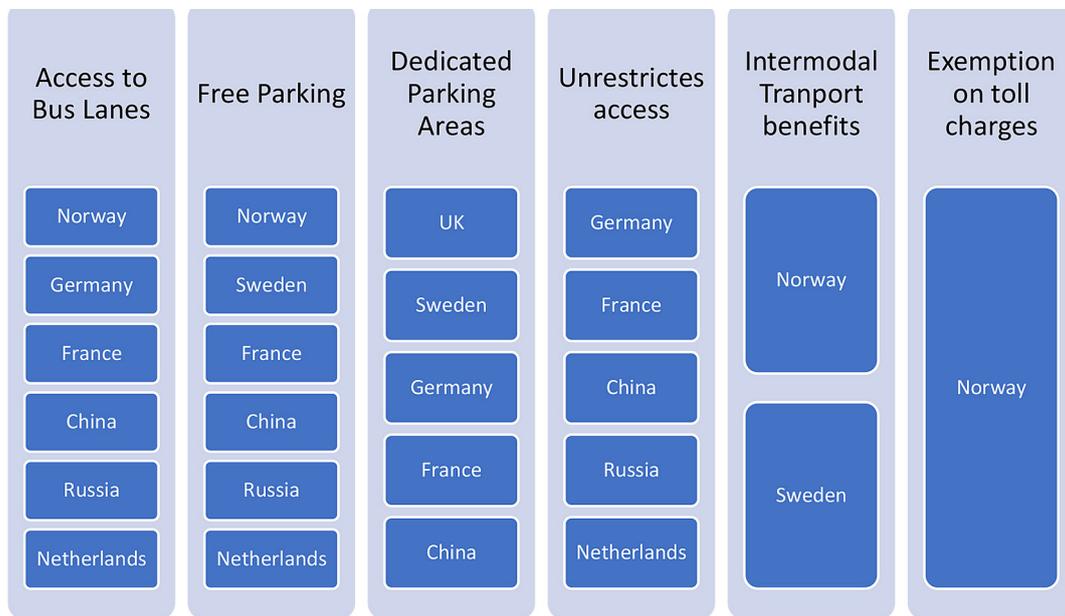


Figure 6. Supporting incentives offered by the majority of developed countries (Niti Aayog and BCG report on accelerating EV adoption)

infrastructure, higher charging times, and a lack of government regulations and incentives. However, recent efforts by certain developing countries have made strides in encouraging the use of EVs.

China

The Chinese government employs various measures, including subsidies, tax incentives,

Table 1. ICEs phase out plan by developed countries (Niti Aayog & BCG report on accelerating EV adoption, 2022)

Country	Phase out year	Country	Phase out year
Iceland	2030	Slovenia	2030
Canada	2040	Netherlands	2030
California	2035	Denmark	2035
Costa Rica	2050	Sweden	2030
Spain	2040	Norway	2030
France	2040	United Kingdom	2035
Ireland	2030	Cape Verde	2035
Germany	2050		

and production regulations, to promote EV use. These policies reduce consumer costs and incentivize automakers to invest in EV production. China's domestic EV sector has been instrumental in its global EV market dominance. Since 2001, China strategically invested in EV technologies, designating EVs as a priority research project in its Five-Year Plan. From 2016 to 2022, the government allocated a substantial \$57 billion to support electric and hybrid vehicles, propelling China to the forefront of global EV production. With multiple domestic automakers producing EVs and spearheading battery technology advancements, China has emerged as a major player in the field of EV manufacturing (Philip Blenkinsop, 2023). The dominant position of China in the global EV market is the outcome of a combination of factors, including government policies, infrastructure investments, and the growth of the domestic EV industry. As other countries and businesses work to spread EVs, China's success can serve as an example for other emerging countries as they create their own strategies.

Brazil

In Brazil, despite being a major global vehicle manufacturer and consumer market, EV diffusion, including BEV and PHEV, remains low at around 1% of licensed vehicles in 2020. Challenges hindering widespread adoption include high initial costs, limited charging infrastructure, and concerns about range limitations and charging times (Costa et al., 2021; Yamamura et al., 2022). Although policies like ANEEL's (Brazil's federal economic regulator for the electricity sector) Normative Resolution No. 819/2018 target uncertainties in recharging infrastructure, barriers

persist. Brazil's history with biofuels, notably ethanol, influences the transport sector, dominated by flex fuel engines, constituting approximately 74% of the 44 million active light vehicles. Despite a 30% growth in EV registrations in 2021, challenges like the insufficient charging infrastructure, ownership costs, tax incidence, and the missing of economic incentives and regulations hinder higher EV diffusion rates.

India

India, being a developing nation, presents socioeconomic indicators below the average when compared to developed economies. Despite government initiatives, India encounters challenges in expediting the diffusion of EVs. The high initial cost of ownership, a lack of charging infrastructure, poor consumer awareness, and demand for EVs all contribute to these problems. The substantial cost disparity between EVs and traditional vehicles stands as a significant hurdle, rendering EVs often excessively expensive for many Indian consumers. Moreover, the lack of government subsidies for EVs further diminishes affordability, hindering widespread diffusion.

The FAME India Scheme, introduced by the Indian government in 2015, intends to encourage the development of EV infrastructure by providing financial incentives to consumers of both BEV and Plug-in Hybrid EVs (MHI Govt of India, 2022). India has implemented a set of measures to bolster EV diffusion, encompassing incentives for EV purchases and a targeted achievement of 30% EVs in the overall vehicle sales by 2030 (Ministerial, 2017). Section 80EEB provides a tax exemption of up to Rs. 1,50,000, complemented by full road tax exemptions in states such as Rajasthan, Andhra Pradesh, Karnataka, Madhya Pradesh, Telangana, Tamil Nadu, Uttarakhand, Punjab,

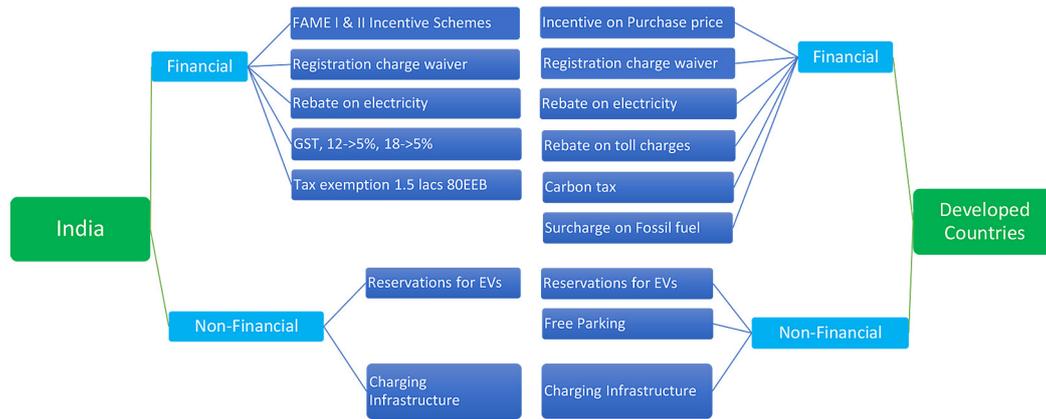


Figure 7. Comparison of EV diffusion model between the developed countries and India

and Uttar Pradesh. Additionally, the central government has reduced the GST component on EVs by 5% (Ruchika Bhagat, 2022). Figure 7 presents a comparative analysis of the EV diffusion model between developed countries and India.

Research gaps

The literature review highlights a considerable body of research investigating the influence of socioeconomic indicators on the diffusion of EVs. These studies underscore the pivotal role of socioeconomic factors in shaping EV diffusion within specific regions. While prior research has yielded valuable insights, but limited to the developed countries. Furthermore, it is worth noting that no significant research could be found on developing nations EV diffusion model given the profound disparities in their socioeconomic indicators compared to developed economies.

THEORETICAL FRAMEWORK

The research utilizes the Roger’s DOI theory to predict EV diffusion. It investigates whether India should adopt the developed countries’ EV diffusion model by studying socioeconomic indicators in both developed and developing nations. In the Figure 8, the researcher tries to establish a cause-and-effect relationship between socioeconomic indicators and EV diffusion barriers. Further linking these barriers to the rogers diffusion of innovation model attributes, aiming to determine the socio-economic indicator’s role in the EV diffusion.

Research hypotheses

1. Hypothesis for research question 1: Does the socioeconomic indicators have noticeable influence on EVs diffusion?

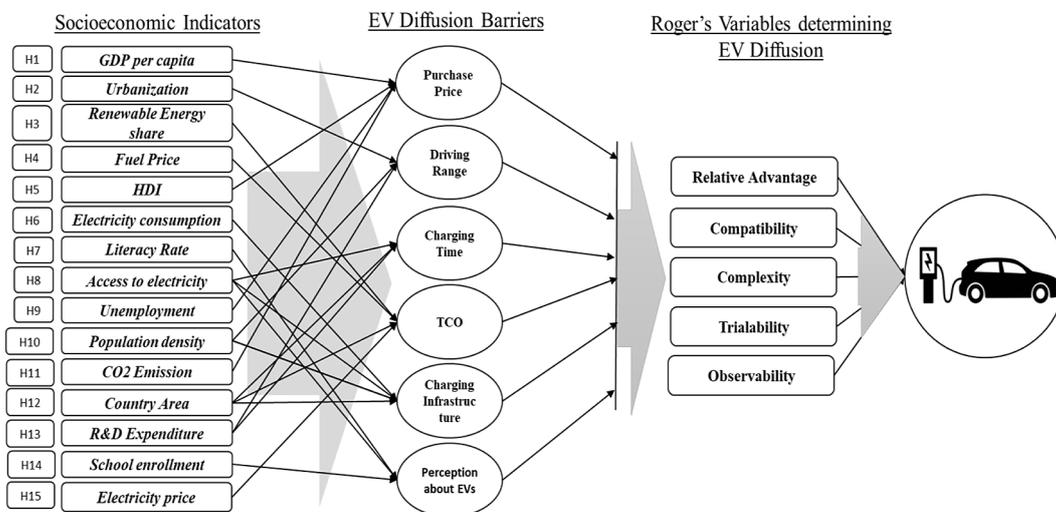


Figure 8. The socioeconomic indicators are mapped to the EV diffusion barriers and finally to the Rogers DOI attributes

- H0 (null hypothesis): socioeconomic indicators have no noticeable impact on EV diffusion.
 - H1 (alternate hypothesis): socioeconomic indicators have a noticeable influence on EV diffusion.
2. Hypothesis for research question 2: Should India adopt the developed countries’ model of EV diffusion?
- H0 (null hypothesis): India shouldn’t adopt the developed countries’ model of EV diffusion.
 - H1 (alternate hypothesis): India should adopt the developed countries’ model of EV diffusion.

METHODOLOGY

Sampling and data collection

In this study, we adopt a descriptive and quantitative methodology. Our dataset comprises secondary data collected from 36 countries across five continents, collectively representing 52% of the global population. The chosen sample includes 28 developed countries and 8 developing countries, selected based on their significant contributions, collectively accounting for over 99% of global EV sales. The criteria for selection also consider the availability of historical data pertaining to EV sales market share.

Data quality and reliability

Ensuring the integrity of our findings is paramount. To achieve this, we meticulously

source data from reputable platforms, including the World Bank, United Nations, and official country websites. This rigorous approach to data collection enhances the quality and reliability of our dataset, laying the foundation for a robust analysis.

Methodology explanation

Our research employs a comprehensive approach to analyze the dynamics of EV diffusion. By utilizing 15 socioeconomic indicators, we delve into the multifaceted aspects influencing the global EV landscape. The Figure 9 explains the method to gain insights into the correlation between various factors and the market dynamics, providing a nuanced understanding of the forces shaping the evolution of EV sales.

Statistical analysis

The examination of collected data utilizes a LOG Transformed Stepwise Multiple Linear Regression (LTSMLR) approach through JMP software. LTSMLR aims to establish a comprehensive understanding of the relationship between socioeconomic indicators and EV diffusion. This method systematically examines the influence of various factors on EV diffusion, providing insights into the intricate interplay between socioeconomic variables and the evolving landscape of EV diffusion.

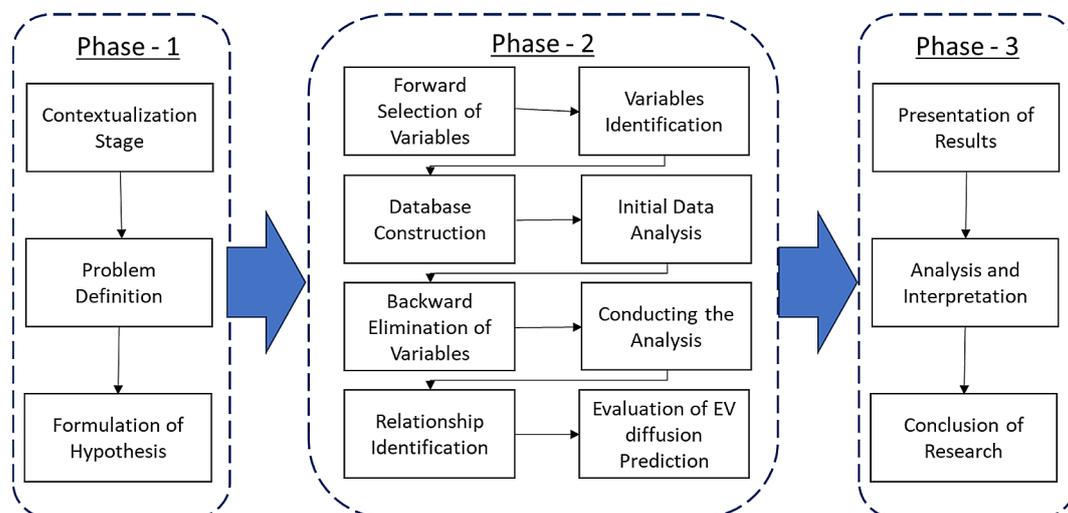


Figure 9. Methodological steps

DATA COLLECTION

The data for this study on the diffusion of EV was collected from various reputed sources, each providing information on specific variables relevant to the research. These variables were chosen to offer a comprehensive knowledge of the factors influencing the diffusion of EVs across many nations, including economic, environmental, and technological considerations (Table 3).

ANALYSIS AND RESULTS

To investigate causal relation between socioeconomic indicators and EV diffusion, we utilize LTSMLR. This approach involves LOG Transformation of variables, forward selection of variables based on a review of the literature, and backward elimination of variables that do not contribute to the model. Commencing with an empty model, variables are incrementally added until no discernible improvement occurs. Subsequently, variables are systematically removed until further elimination has minimal influence on the model. The criteria for variable inclusion or exclusion are typically based on statistical measures, including p-values and adjusted R-squared.

Forward selection

Through the forward selection based on insights from the literature review by Ribeiro and

Ruoso (2022), Briseño et al. (2021), Kim et al. (2014), Jensen et al. (2013), the following independent variables were chosen: urbanization, population density per square kilometer, GDP/PC, renewable energy share, gasoline price, diesel price, country area in 1000 sqkm, literacy rate, unemployment rate, access to electricity, electric power consumption in kWh, HDI, CO₂ emission per capita, research and development expenditure, and secondary school enrollment.

Backward elimination

From the initially chosen 15 independent variables out of forward selection, the 7 independent variables were methodically excluded based on criteria encompassing multicollinearity, p-value, and their overall contribution to the model: gasoline price, diesel price, country area in 1000 sqkm, literacy rate, unemployment rate, access to electricity, CO₂ emission per capita, research and development expenditure, and secondary school enrollment. In the Figure 10 the theoretical framework is reconstructed post backward elimination of independent variables.

Outcome of the analysis

The results, with a p-value below 0.001, demonstrate a highly significant connection between independent and dependent variables. The model exhibits strong explanatory power, with an Adjusted R-squared value of 0.781,

Table 2. EV subsidies in the various developed economies

Country		Subsidy	Upfront tax reduction	Recurring tax reduction
Europe	Germany	9,000 (if VC < €40K) €12,000 (if €65K > VC > €40K)	-	Road tax exempt for 10 years (~€200/year)
	Sweden	€6,000	-	Road tax exempt for 5 years (~€170/year)
	Finland	-	-	5-year annual tax exempt, post 5 years 75% lower vs ICE
	Norway	-	VAT exempt (~25% of cost)	-
	UK	£1,500 (if VC < £32,000)	-	Road tax exempt (vs £145–£335 for ICE)
Others		USA	\$2,500–7,500 income tax credit available	
	Japan	JPY	No purchase tax (vs 3–5% for ICE)	Road tax exempt (vs \$75–275 for ICE); Weight tax (vs \$45/ton for ICE)
	China	RMB 9,000–13,000	No purchase tax (vs 10% cost of ICE)	-
	Australia	AUD 3,000	Stamp duty exempt (50–100% lower than ICE)	Annual registration fee subsidy (30–100% lower than ICE)

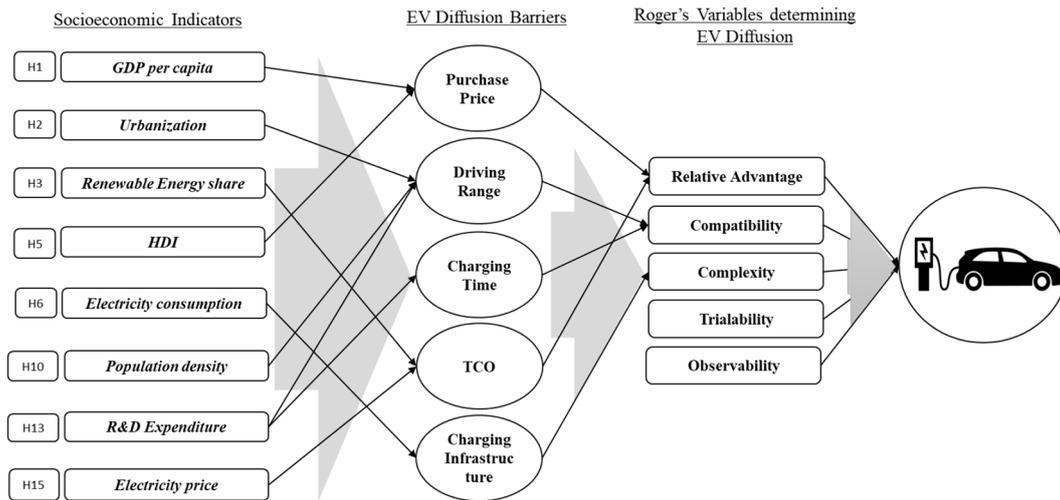


Figure 10. The theoretical framework reconstructed post backward elimination

indicating that about 78.1% of the dependent variable's variation can be explained by the independent variables. The root mean square error (8.88) suggests a reasonable predictive accuracy, with an average error of approximately 8 units. Mean square values and an F Ratio (15.88) confirm the model's effectiveness in explaining variability. With a sample size of 36 observations, the findings are reasonably reliable, providing valuable insights for further research and practical applications, emphasizing the importance of considering independent variables in analyzing and predicting the dependent variable (Table 4, Table 5).

The p value of each selected socioeconomic indicators is specified in the Figure 11.

The intercept signifies the baseline value of the dependent variable when all independent variables are zero, and it's statistically significant, indicating a non-zero baseline. Significant relationships are observed between the dependent variable and certain independent variables – e.g., GDP per capita, log_urbanization, log_renewable energy, Log_ElectricityKwh/capita, log_population density and Log_R&Dexpenses with statistically significant positive coefficients. Conversely, log_HDI and log_Electricity prices lack statistically significant relationships, suggesting minimal impact in the current model. VIF values, assessing multicollinearity, are mostly below 5, indicating low multicollinearity. However, log_HDI exhibits a VIF of 6.52, indicating moderate multicollinearity.

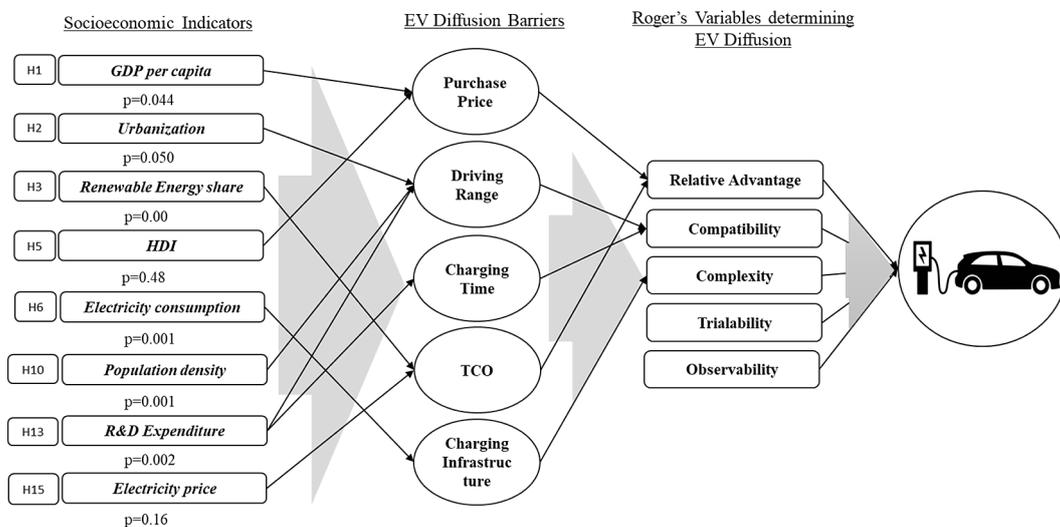


Figure 11. The p value from the analysis is mentioned below each indicator

Table 3. The source of data for the predictor variables that have a substantial contribution to the model

Type	Variable	Definition and source	
Response variable	Share of EV diffusion	Definition:	Share of EV adoption 2021/2022
		Units:	In percentage
		Data sources:	https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf https://www.euronews.com/next/2023/02/20/sales-of-electric-cars-in-the-eu-broke-records-in-2022-which-country-in-europe-is-leading https://parivahan.gov.in/parivahan/ https://en.wikipedia.org/wiki/Electric_car_use_by_country
		Retrieved on:	20-11-2023
Independent variable	GDP per capita	Definition:	GDP per Capita in 2022
		Units:	in USD
		Data sources:	https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
		Retrieved on:	20-11-2023
	Log_urbanization	Definition:	Population present in the urban area in 2022
		Units:	In percentage
		Data sources:	https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS
	Log_renewable energy	Definition:	Renewable energy share
		Units:	In % in 2021/22
		Data sources:	https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/RESHARE_2023_cycle2.px/table/tableViewLayout1/ https://www.statista.com/ https://ourworldindata.org/grapher/share-electricity-renewables?tab=table
		Retrieved on:	20-11-2023
	Log_HDI	Definition:	Human Development Index in 2022
		Units:	HDI Index 2021
		Data sources:	https://hdr.undp.org/data-center/human-development-index#/indicies/HDI
		Retrieved on:	20-11-2023
	Log_electricity Kwh/Capita	Definition:	Electricity consumption in 2022
		Units:	In Kwh/Capita
		Data sources:	https://ourworldindata.org/energy-production-consumption
		Retrieved on:	20-11-2023
	Log_population density	Definition:	Population density in 2021
		Units:	Density per Km
		Data sources:	https://data.worldbank.org/indicator/EN.POP.DNST
		Retrieved on:	20-11-2023
	Log_R&D expenses	Definition:	Research and development 2022
Units:		Expenditure in % of GDP	
Data sources:		https://ourworldindata.org/grapher/research-spending-gdp	
Retrieved on:		20-11-2023	
Log_ElectrPrices*85	Definition:	Electricity price 2022	
	Units:	in Rs per Kwh	
	Data sources:	https://www.globalpetrolprices.com/electricity_prices/	
	Retrieved on:	20-11-2023	

Table 4. Summary of Fit and ANOVA

Summary of fit				
RSquare			0.831783	
RSquare Adj			0.781941	
Root mean square error			8.885112	
Mean of response			15.88995	
Observations (or sum Wgts)			36	
Analysis of variance (ANOVA)				
Source	DF	Sum of squares	Mean square	F ratio
Model	8	10539.768	1317.47	16.6884
Error	27	2131.521	78.95	Prob > F
C. Total	35	12671.289		<.0001

Table 5. Parameters effect output from JMP software with p value & Multicollinearity value in terms of VIF

Independent variable	Estimate	Std error	t Ratio	Prob > t	VIF (multiple collinearity)
Intercept	-236.9352	166.6964	-1.42	0.1667	.
GDP per capita in 2021	0.0001549	7.35E-05	2.11	0.0446	1.9734287
Log_Urbanization	53.991801	26.3554	2.05	0.0503	2.5549607
Log_Renewable energy	47.280266	6.418892	7.37	<.0001	2.6290936
Log_HDI	-74.61868	104.2831	-0.72	0.4804	6.5218167
Log_ElectricityKwh/capita	55.70187	9.532228	5.84	<.0001	3.8017294
Log_Population Density	20.474226	3.705343	5.53	<.0001	3.0358539
Log_R&Dexpenses	-27.11743	8.075181	-3.36	0.0023	2.4717844
Log_ElectrPrices*85	-11.32356	7.853228	-1.44	0.1608	2.6726843

DISCUSSION

The difference in EV diffusion rates between developed and developing economies can be attributed to significant variation in socioeconomic indicators and the associated barriers to EV diffusion. Developed nations such as Norway, Sweden, Iceland, Denmark, UK, Germany and France demonstrate early adoption of EVs, driven by favorable socio-economic indicators including higher GDP per capita, urbanization, renewable energy share, population density, and R&D expenditure. The robust state of these socioeconomic indicators helps to overcome EV diffusion barriers, providing a relative advantage over conventional vehicles. In the framework of Rogers’ DOI theory, key attributes such as relative advantage, compatibility, and complexity play pivotal roles in propelling diffusion of EVs due to the reduced barriers. To navigate these challenges, India must adopt a distinctive approach tailored to its unique context, reinforcing the ecosystem supporting electrification efforts.

Answering research question

Research question 1: Does the socioeconomic indicators have noticeable influence on EVs diffusion?

Based on the results of the analysis, it is evident that socioeconomic indicators exert a discernible influence on the diffusion of EVs. Consequently, the null hypothesis, positing no such influence, is rejected, while the alternative hypothesis, asserting a significant impact of socioeconomic indicators on EV diffusion, is accepted based on the statistical analysis.

Research question 2: Should India adopt the developed countries model of EV diffusion?

Research question investigates the feasibility of India adopting the developed countries’ model of EV diffusion. The literature review reveals a prevalent trend in developed nations where successful EV penetration is achieved through strategies that incentivize adoption, making EV costs comparable to conventional vehicles. Additional

policy measures, such as carbon taxes on conventional vehicles, free parking for EVs, access to bus lanes, and discounted charging facilities, have proven effective. However, it is imperative to acknowledge that these policies, while successful, come with a financial cost. Developed nations, leveraging their robust financial capabilities, can afford to provide such incentives. In contrast, emerging economies like India face financial constraints and prioritize meeting basic citizen needs. Consequently, the diffusion of the developed countries' model of EV diffusion may not be a practical or prudent approach for India. The distinct financial circumstances and primary responsibilities of developing nations necessitate a contextually relevant strategy for the widespread adoption of EVs.

CONCLUSIONS

Our research reveals a significant link between socioeconomic indicators and EV diffusion, emphasizing the need for tailored strategies. For India, a universal approach, especially borrowed from developed economies, may prove ineffective. Instead, insights from China, aligning more closely with India's socioeconomic context, offer valuable lessons. To steer toward sustainable transportation, India must adopt a balanced approach, considering environmental goals and economic realities. Managing affordability, infrastructure, and incentives is crucial for a seamless transition to electric mobility, addressing socioeconomic challenges effectively. This approach positions India for success in building a greener and economically viable transportation landscape.

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