DRIVERS OF GLOBAL ELECTRIC VEHICLE (EVs) ADOPTION: A COMPREHENSIVE ANALYSIS OF POLICY, INFRASTRUCTURE, AND SOCIO-ECONOMIC FACTORS

A Thesis

Submitted to the Master's Study Program of Economics at the Faculty of Economics and Business in partial fulfilment of the requirements for the degree of

Master of Arts (M.A)

By:
Rahmat Olii
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UNIVERSITAS ISLAM INTERNASIONAL INDONESIA
DEPOK
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" *Hello Olii here, this master journey has taught me that big dreams demand great perseverance. Every moment of exhaustion, every tear, and every prayer is part of the story that shapes who I am today. To my father in heaven, my mother, my family, my friends, and all who believed in me this work is proof that your faith and support have never been in vain. I am proud to be the first in my family to earn a Master's degree, and I dedicate this achievement to all of you. May this small step be the beginning of a greater journey to bring positive change and benefit to many*."

Depok, 05 August 2025

ABSTRACT

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This study aims to analyse the relationship between policy, infrastructure and socio-economic factors specifically measured by environmental awareness, fuel prices and per capita income on electric vehicle adoption from 2018-2023 in two country grouping classifications namely countries with the most electric vehicle adoption and countries with emerging electric vehicle adoption. This country grouping is based on the International Energy Agency (IEA) reference. This study uses a panel data regression model, fixed effects for measurement (model 1), namely the classification of all countries combined, the Random Effects model for (model 2), namely the country with the most electric vehicle adoption and the Common Effects Model for (model3), namely the countries with emerging electric vehicle adoption. This research concentrates on (Models 1 & 2). The results show that policies and infrastructure variable have a significant and positive effect on electric vehicle adoption in both country classification models, namely in country classification (models 2 & 3). These results illustrate the important role of the state as a key institutional actor driving the electric transportation transformation. and it shows that charging infrastructure is a significant driver of EV adoption even in the early days of the market. The socio-economic factors of environmental awareness and income per capita do not have a positive significant effect on the countries classified in (model 2), but the fuel price variable has a positive significant effect in this model, indicating that the countries with the most EV adoption means that the penetration rate of electric vehicles is determined more by existing infrastructure and strong policy support, rather than socio-economic factors. In addition, higher fuel prices may encourage consumers to purchase EV as a more affordable operating option. Meanwhile, there is no significant positive effect of the three socio-economic variables on EV adoption in the country classification of (model 3), which suggests that socio-economic factors do not prove to be important as EV adoption in these countries is currently constrained by other structural factors, Individual decisions are heavily influenced by factors such as lack of charging infrastructure and lack of incentives or regulations. Therefore, despite increased environmental sensitivity, the growth of EV remains limited. The study implies that policies and infrastructure play a very important role in the adoption of EV in the countries studied, with supportive regulations, fiscal incentives, and provision of adequate charging infrastructure shown to accelerate the penetration of EV adoption.

Keywords: *Electric Vehicle, Policy, Infrastructure, Charging Station, Clean Technology, Panel Data, IEA*

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ABBREVIATIONS DIRECTORY

EVs	: *Electrical Vehicle*
BEVs	: *Battery Electric Vehicle*
HEVs	: *Hybrid Electric Vehicle*
FCEVs	: *Fuel cell Electric Vehicle*
PHEVs	: *Plug-in Hybrid Electric Vehicle*
EVI	: *Electrical Vehicle Index*
IEA	: *International Energy Agency*

CHAPTER I
INTRODUCTION

1.1. Background

Electric vehicles (EVs) were first introduced around the end of the 1800s. Since the technology has advanced and prices have decreased, electric vehicles (EVs) have become more and more popular. Additionally, support for clean transportation has raised awareness, expanded access to charging stations, and made it easier for EV adoption. As a result, a substantial amount of literature has been written about EVs and their functions in energy and transportation networks. Mursatori, M., et al. (2021). Growth Sales of the current car fleet will shift in the coming years from conventionally fuelled vehicles to electric vehicles (EVs), particularly light passenger cars. As EVs are connected to the power grid and use rechargeable batteries to store electricity, distribution networks will face various difficulties as EV adoption increases. Given the uncertainty surrounding the likely evolution of EV sales, it is difficult to predict how EVs will affect distribution networks. Nogueira, t et al. (2022).

EVs success has been rising quickly since the middle of the decade. Every year, EVs sales surpass past records, particularly for buses, light-duty vehicles (LDVs), and smaller vehicles like e-bikes, mopeds, kick-scooters, and three-wheelers. (IEA 2017; IEA 2018a; ˙IEA 2019; IEA 2020). Rapid technology advancement and governmental policy incentives are driving the growth of electric vehicles (EVs) and renewable clean energy (RCE) power grid systems. Sales of EVs increased from 7.5 million in 2019 to over 40 million in 2023, with battery electric cars (BEVs) accounting for 70% of these sales. By 2030, EV stocks are expected to reach 250 million. (Global EV Outlook 2023 & Global EV Outlook 2024). Although the growth of EVs appears to be inevitable, it is challenging to forecast when it will occur, particularly if the global economy slows down and or governments remove or impose more regulations or subsidies to encourage the adoption of EVs. Duncan, M. P. (2019). The shift to a low-carbon transportation system will be dominated by electric vehicles. Learning rates aid in quantifying the historical rate and pace of change for new transportation options, the interplay between system-wide and technology-specific changes, and the economics of various policy options as we monitor and predict this evolution. Kittner, N, et al (2020). Growth and electric vehicles are potential solutions to the negative impacts of worldwide urbanization on air pollution and health. However, the effects of planning strategies on distinct types of pollutants. Yu, H., & Stuart, A. L. (2017).

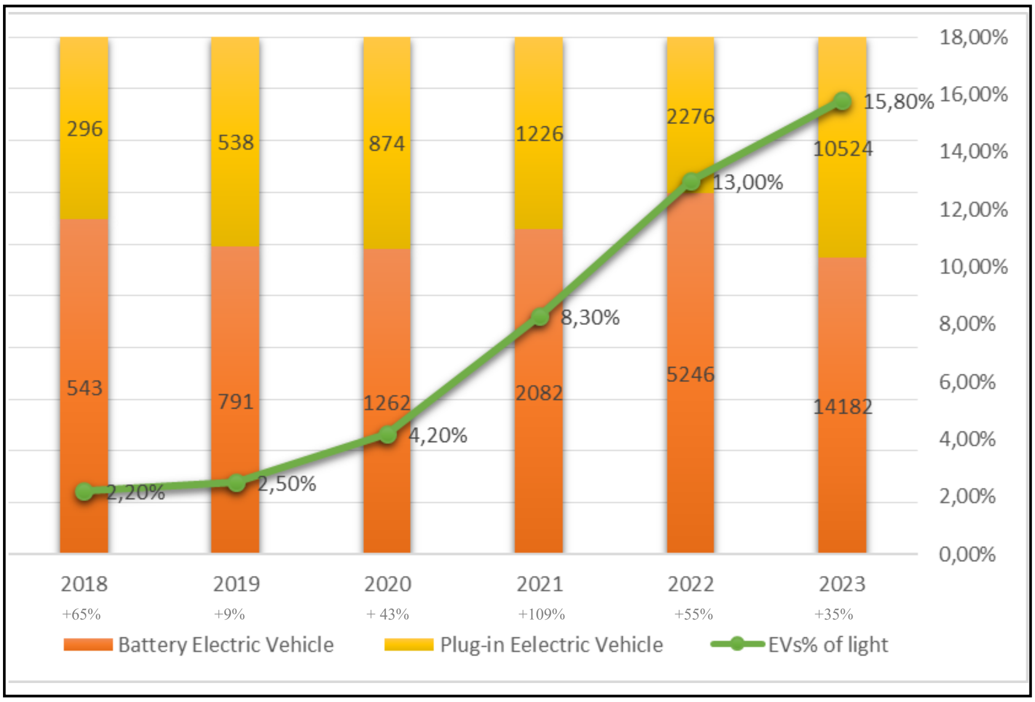


Figure 1.1. Global BEVs & PHEVs Sales (000's) 2018 - 2023

Sources : EV-Volumes. (2024a)

Reaching 14.2 million units in 2023, Global Electric Vehicle (EV) sales—including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—show a 35% year-on-year rise. Of this overall, 4.2 million were PHEVs and Range Extender EVs (EREVs), and 10 million were BEVs. With five months of the year setting all-time monthly sales records, the growth added 3.66 million units above 2022. Germany observed a fall because of subsidy reduction, whereas EV development was constant worldwide. Europe had a meagre 17% gain, which, eliminating Germany, would be 32%. From a low basis, China's EV sales increased by 36%; North America's by 46%; other countries by 81%. Rising from 13.0% in 2022, EVs accounted for 15.8% of total light vehicle sales worldwide in 2023 (BEVs 11.1%, PHEVs 4.7%). Following Norway (BEVs 72%), PHEVs 7%, Hong

Kong and Nordic nations came second with largest market shares. Rising markets such Malaysia (+886%), Turkey (+805%), Brazil (+359%), Thailand (+328%), and Australia (+141%), showed fast expansion.

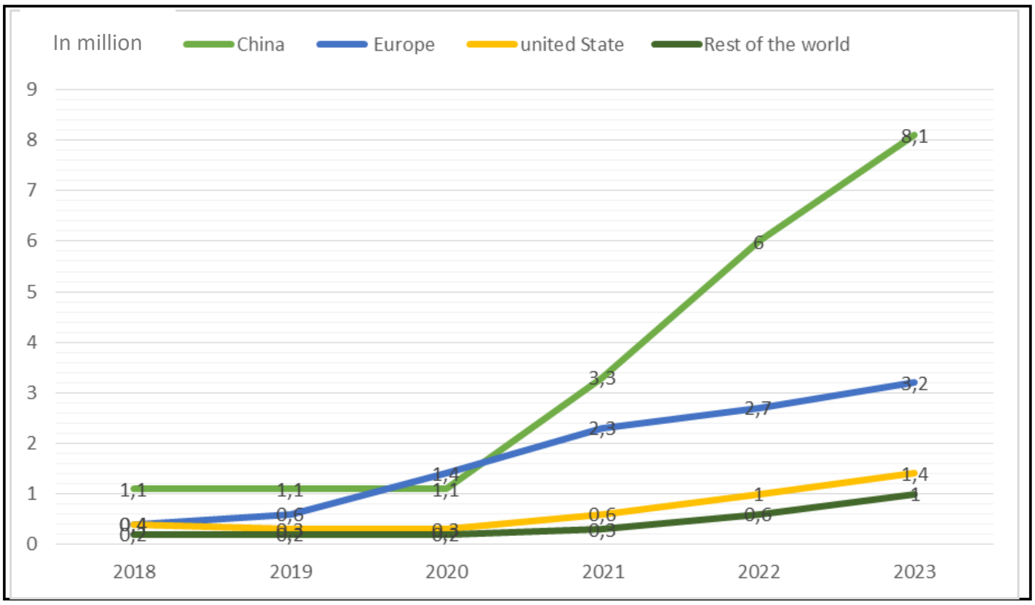


Figure 1.2. Electric Vehicle Sales by region

Sources : IEA. (2024a)

Global electric vehicle sales remained on track at the start of 2023. By 2023, 14.2 million new Battery Electric Vehicles (BEVs) and Plug-in Hybrids (PHEVs) will have been delivered, reflecting growth of 35%. 10 million are battery electric vehicles (BEVs), while 4.2 million include plug-in hybrids (PHEVs) and electric range extender vehicles (EREVs). Media statements regarding a slowdown in EV acceptance are not supported by our monthly tracking data. Global BEV and PHEV deliveries rose to 3.66 million units in 2022, with monthly sales ranging from 8% to 52% more than the previous year. In the first five months of 2023, electric vehicle sales reached unprecedented levels, accompanied by a steady increase in market share throughout the year. Germany, Europe's largest EVs market, saw a decline in EVs sales and market share due to a substantial reduction in EV grants. Electric vehicle registrations in Europe increased by about 17% compared to 2022; except for Germany, the increase reached 32%. Electric vehicle sales in China increased 36% year-on-year in 2023, while sales in the United States and Canada jumped 46%

compared to the previous year. Electric vehicle sales in markets outside these regions increased 81%, albeit from a minimal starting point. IEA. (2023).

In 2023, EVs sales are supported by an overall recovery in the vehicle market, reflecting an increase of 10.5% compared to 2022. In 2024, global Light Vehicle sales growth is anticipated to be lower and more variable, with overall vehicle sales likely to decline in China. In Q4 2023, volumes were comparable to the sales increase in Q4 2022, prior to the implementation of incentive reductions in January 2023, particularly in China, Germany and Norway. EV sales grew 29% in Q4, compared to a total increase of 35% for the whole of 2023. The rise in EVs, continued financial incentives, advances in charging infrastructure and a focus on the environment continue to drive EV growth. OEMs are lowering prices where margins allow, which serves as an additional impetus for increased sales. Global EV sales are projected to reach 17.8 million units in 2024, representing a market share of 19.6% of total light vehicle sales. Electric vehicle sales rose 25% in a global light vehicle market that grew by 1%. EV-Volumes. (2024b)

BEVs share of 41% in China, with year-on-year volume growth of 17% to 9.8 million BEV and PHEV units, which is lower than CPCA's forecast, as they project an increase in overall vehicle sales. Provinces can provide vehicle sales incentives to support their local original equipment manufacturers (OEMs). This includes internal combustion engine vehicles, which are hampering the expansion of EV market share. BEV and PHEV sales in the US and Canada will increase by 56%, resulting in a 13.8% share of total light vehicle sales. The Inflation Reduction Act (IRA) is encouraging EV growth in the US, contingent on a clearer understanding of the complex requirements for grants. Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) manufactured in the United States, Canada, and Mexico accounted for about 77% of total Plug-in Electric Vehicle (PEV) sales in the United States last year; we anticipate this proportion to increase in 2024.

Reduced subsidies and achieved CO2 compliance are constraining volume and market share growth for electric vehicles in Europe compared to the surge seen in 2020 and 2021. In 2024, we anticipate EV sales to increase by 22% in Europe compared to 2023, as EV subsidy reductions end in many countries and annual tax savings relative to internal combustion engine vehicles remain unchanged. Specialized EV manufacturers will experience significant growth as many traditional original equipment manufacturers focus on profit margins rather than maximizing sales. EV-Volumes. (2024c)

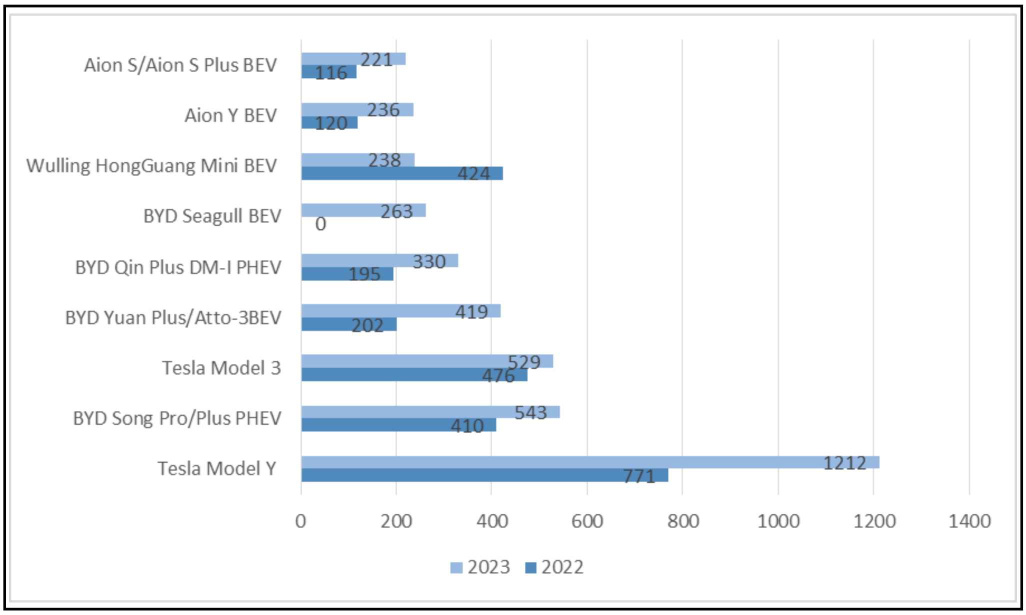


Figure 1.3. Top 10 EV Model's Global-Deliveries (000's) 2022 vs 2023.

Sources : EV-Volumes. (2024a)

Three million units (+62% YoY) including 1.44 million PHEVs, BYD dominated worldwide electric vehicle sales; Tesla maintained its lead in BEV sales with 1.81 million units (+38%). In terms of sales growth, pure electric car manufacturers surpassed established car manufacturers. The predicted 40 million global electric vehicle fleet by the end of 2023 consists of 70% BEVs and 30% PHEVs. The forecast for 2024 shows 12.8 million BEVs and 5 million PHEVs among 17.8 million electric car sales (+25%).

Furthermore, more aggressive regulations are currently being adopted by countries, states, and localities to encourage the use of electric vehicles. These tactics are increasingly widespread and are expected to expand and be implemented in the future. Around the world, many municipal and federal governments have stepped up their efforts to make electric vehicles more widely available. Notable more recent examples include the high percentage of electric vehicle ownership in

Oslo and Shenzhen's full investment in electric city buses and taxis. By 2025, legislators in California hope to have one million electric cars on the road. Kittner, N et al. (2020). Policies that systematically lower EV prices can be implemented to increase EVs cost competitiveness. For example, greater costs related to increasing battery capacity can be reduced with EV discount programs that focus more (even more on the current policy) on EV battery cost components than on the overall cost of EVs. In addition, the EVs may face challenges to the ICEV for a while due to varying gas prices. If consumers do not consider total environmental hospitality when purchasing a car, the cost of refuelling EVs will become less profitable due to lower gas prices and more efficient combustion engines. Adepetu, A., & Keshav, S. (2017a).

EVs adoption is frequently encouraged without taking into account the complete environmental impact of EVs at every stage of their life cycle, from pre-manufacturing to disposal. Since the power mix's composition affects how EVs affect the environment, a thorough environmental impact assessment that takes the country's power mix into account should be carried out. Shepherd, S, et al. (2012). According Kim, S et al. (2019), compared the possible effects of ICEVs and battery electric vehicles (BEVs) across a number of categories. Based on South Korea's national power roadmap, they also evaluated the country's power portfolio for the environmental effects of BEV. Few research have used both EV predictions and the The environmental impact of Electric Vehicles (EVs) requires an analysis of the national power mix. Several recent studies have focused on the environmental performance of EVs, comparing them with ICEVs. To accurately predict the potential environmental impact of EVs, the share of national electricity generation and subsidy policies to promote EVs should be taken into account, while also addressing climate change issues. Given the increasing number of EVs and concerns about climate change, estimating their potential environmental aspects compared to national electricity production is important to include projections of EV migration. According to Kim et al. (2021), EVs have significantly lower energy requirements than conventional cars, implying significant reductions in greenhouse gas emissions associated with this type of road vehicles. Humayro, A., & Virgianita, A. (2024).

1.2. Problem of Statement

The global shift towards sustainable mobility is driven by the widespread adoption of electric vehicles (EVs), which are a fundamental solution to reducing greenhouse gas emissions and dependence on fossil fuels. Adoption rates fluctuate significantly by country and region, despite advances in EV technology. (EEA. (2015), Reuters. (2024), World Bank. (2022). These disparities raise important questions about the underlying factors driving or hindering global electric vehicle adoption. Many regions continue to experience slow EV adoption despite the urgent need to address climate change and the emergence of enabling technologies. Existing research has examined individual factors-such as government legislation, charging infrastructure and consumer income levels-but lacks a comprehensive cross-country analysis that integrates these factors to assess their significance and interrelationships.

In addition, while tax incentives and subsidies are generally considered significant, their interaction with infrastructure readiness and socio-economic factors such as environmental awareness, per capita income and fuel price c is unclear. This fragmented knowledge makes it difficult for environmental agencies, legislators and manufacturers to formulate effective strategies to accelerate the adoption of electric vehicles. This study seeks to address this gap by comprehensively examining the key factors influencing global electric vehicle adoption. The study aims to identify critical aspects by examining a combination of policy measures, infrastructure capabilities, and socio-economic features, thereby providing evidence-based insights to guide future electric vehicle development and global policy frameworks.

1.3. Research Objective

The adoption of electric vehicles, which is presented in the number of sales of electric vehicles in the world, needs to know the factors that influence it. Therefore, this study was conducted to explore the adoption of electric vehicles in the world, which is measured against several variable factors, namely, the impact of the role of government policies, infrastructure represented by charging stations and three variables representing socio-economic factors, namely income per capita, environmental awareness, fuel price, where the emphasis of the three socio-economic variables is income per capita, affecting consumption preferences, including the decision to buy a vehicle (EV are more expensive than conventional vehicles), environmental awareness, relating to the values, norms, and behaviour of society towards environmental issues that can affect the decision to purchase EVs. fuel price, which affects the operating costs of conventional vehicles, thus impacting the relative attractiveness of EVs. To support the research, this study also utilizes a set of control variables identified as factors that may influence a country's EV adoption, which consist of population, urbanization.

1.4. Research Questions

Based on the background stated above, the research questions of this study can be formulated:

1. How do government policies influence global electric vehicle (EV) adoption sales?
2. To what extent does the availability of infrastructure (charging stations) drive EV adoption across different countries?
3. How do socio-economic factors—such as per capita income, fuel price, and environmental awareness the demand for electric vehicles?

1.5. Research Hypothesis

1. H1 : Government Policy Significantly Impact EV Adoption
   H0 : Government Policy has no Impact EV Adoption
2. H1 : Infrastructure (Charging Station) Significantly Impact EV Adoption
   H0 : Infrastructure (Charging Station) has no Impact EV Adoption
3. H1 : Socio-economics factor, per capita income, fuel price and environmental awareness Significantly Impact EV Adoption
   H0 : Socio-economics factor, per capita income, fuel price and environmental awareness has no Impact EV Adoption

1.6. Research Significance

1.6.1. Theoretically

By incorporating ideas from various theories including Diffusion of Innovations and Institutional Theory, this study theoretically makes a significant contribution to the growing literature on the acceptance of green technologies, particularly electric vehicles (EVs). The paper advances scientific knowledge on the interplay between government regulations, charging infrastructure, and socioeconomic factors to encourage or hinder the adoption of electric vehicles around the world.

1.6.2. Practically

Practically, the findings of this study help investors, the automotive sector and legislators to make more successful plans to accelerate the transition to sustainable transportation. In setting financial incentives, developing equitable infrastructure, and raising public awareness about electric vehicles in different countries, the empirical results can be a source of inspiration.

1.7. Research Outline

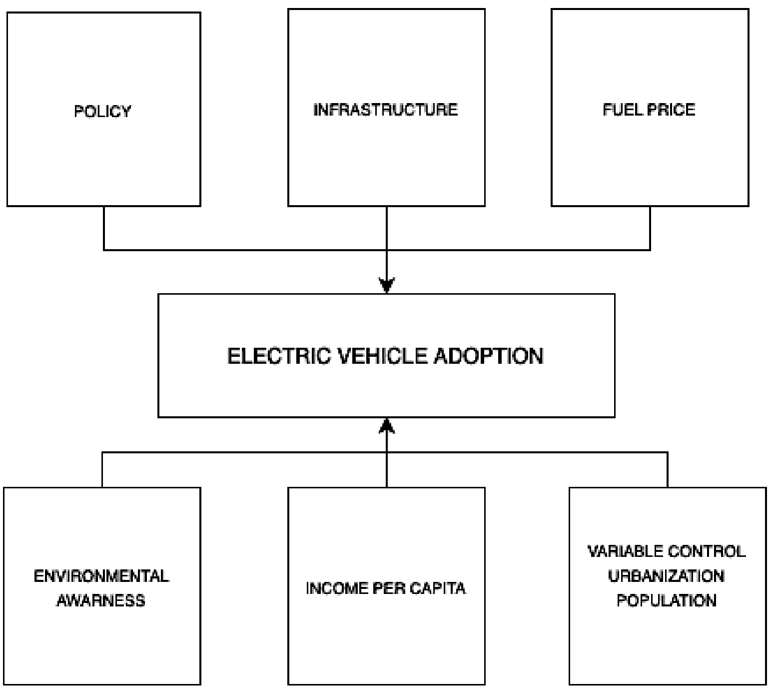
This research paper aims to investigate the factors contributing to the adoption of electric vehicles in selected countries around the world, focusing on policy, infrastructure, and socio-economic factors including per capita income, fuel prices, and environmental awareness. The paper is organized into five chapters, starting with an introduction that explains the background of the problem and the research questions. Chapter 2 reviews the relevant literature on electric vehicle adoption as measured by sales volume and its influencing factors. Chapter 3 discusses the research methodology, including data collection and analysis methods. Chapter 4 presents the findings and discussion on the relationship between all variables including government policies, infrastructure and technology, as well as socioeconomic factors including per capita income, fuel prices and environmental awareness. Finally, Chapter 5 presents the conclusions, research limitations, policy implications, and suggestions for future research.

CHAPTER II
LITERATURE REVIEWS

2.1.Conceptual Framework

This literature analysis seeks to explain the impact of government policies, infrastructure, and socio-economic factors-such as per capita income, fuel prices, and environmental awareness-on the adoption of electric vehicles. This section will review the relevant literature, starting with the growth trajectory of the electric car market. This study incorporates supporting variables, particularly control variables such as Urbanization and Population, to enhance the analysis results, as illustrated in the following conceptual framework 2.1.

Figure 2.1. Conceptual Framework



Sources : Author's Compilation

2.2. Theoretical Background

2.2.1. Definition and Concept of Electric Vehicle

The 1980s and 1990s marked the beginning of experiments that specifically defined EVs as living entities with enzymatic and functional capabilities. A number of studies conducted prior to this time period either hinted at the possibility of structures that were later referred to as EVs or described experiments that we can infer involved EV activity. In this way, the history of EV research probably began with coagulation studies. Couch, Y, et al .(2021). A period of growth and more focused knowledge in EV research began in the early 1980s. Coherence began here, although the substantial explosion of papers, theories, and conflicts over nomenclature and societies associated with EV would not begin for another 20 years or so. The Johnstone and Stahl laboratories produced two important and complementary publications that defined mast exosomes and provided convincing arguments for the release of intraluminal vesicles from cells.(Harding. Et al (1983 , & Pan, B. T., & Johnstone, R. M. (1983). Rose Johnstone's early speeches may have contributed to the global perception of EVs as simply "waste disposal mechanisms" over the next ten years, in addition to establishing one of the distinguishing characteristics of the EV vernacular. She delivered the Jeanne Manery-Fisher Memorial Lecture in 1991, titled "Reticulocyte maturation: exosome formation as a mechanism for membrane protein release." Her paper from that year, in which she proposed that exosomes are "the primary route for externalization of obsolete membrane proteins," became the primary basis for his talk. Johnstone, R. M. et al. (1991).

In general, electric vehicles are categorized in four categories: fuel cell electric vehicles (FCEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and battery electric vehicles (BEVs). Among these, BEVs operate using an electric motor that is powered solely by a battery. Zhang, Q. et al. (2018). EVs use more energy-efficient powertrain technology, such as regenerative braking, which reduces energy loss, in contrast to ICE vehicles. The device can capture the vehicle's kinetic energy when it is braking and use motors to replenish the batteries. Additionally, when EVs are stationary, they don't use any energy. Kihm, A., & Trommer, S. (2014). Furthermore, electric motors can produce maximum torque throughout their entire speed range, which means that electric vehicles (EVs) do not require a gearbox for power transmission and propulsion. The absence of a gearbox reduces energy losses and overall vehicle weight, thereby enhancing the energy efficiency of EVs. Many studies have explored the role of EVs in reducing greenhouse gas emissions, with one research group finding significant insights regarding this impact on a broader scale. Peng, T., Ou, X., & Yan, X. (2018). Electric vehicles (EVs) are becoming an appealing option for many people, due to reasons such as reduced cost and increased awareness of climate and environmental deterioration. Together with public transportation, sharing, and other components, EVs are expected to be a key part of future smart cities. Thus, further advancements in battery power and charging need to be made. A significant drawback of EVs is their range, but some scientists are developing novel battery solutions to extend range while reducing weight, cost, and charging time. Ultimately, the success or failure of EVs will depend on these factors. Sanguesa, J. A., et al. (2021). Plug-in electric vehicles, known as battery electric vehicles (BEVs), use an off-board source of electricity to power an electric motor. These vehicles do not operate on liquid fuel and lack internal combustion engines. BEVs generally rely on sizable battery packs to offer a commendable range. While certain models can achieve distances of up to 500 kilometres with one charge, the typical range for most BEVs falls between 160 and 250 kilometres. A prime example of this category is the Nissan Leaf. InsideEVs. (2019).

2.2.2. Types and models of electric vehicles

There are various new electric vehicles, which build on 19th- and 20th-century innovations. Broadly, these vehicles can be broken down into 6 categories. Today's most widely produced electric car is the battery electric car, which makes use of chemical energy stored in rechargeable battery packs. Hybrid vehicles combine electric motors and other power sources, such as internal combustion engines, with their own or with power cables. Some cars are powered by metal-air fuel cells, using metals capable of oxidizing in air to release solar energy, while electric cars use energy that originates from renewable energy sources which have been harnessed by common grid energy. Some vehicles include solar panels, which can be used to power a/c to cool the car before you get in. Power is drawn from one or more off-board power sources, while there are also vehicles that draw power from another vehicle. Power cable is the most common form of this. Sources can be recharged every two to ten hours. Electric cars include a variety of energy storage systems such as batteries, flywheels, and supercapacitors, to store electricity to be harnessed when needed. Electric ships and trains and airplanes etc. too, for good measure. That being said, this book is mostly concerned with autonomous wheeled vehicles. Larminie, J., & Lowry, J. (2012).

Table 2.1. Type of Electric Vehicle

Type of EV	Description	Example
Battery Electric Vehicle	BEV is a Fully Electric Vehicle. A battery-powered electric drivetrain is the only power source for a BEV. A large battery, which can be charged by connecting it to the power grid, stores the electricity needed to power the vehicle. One or more electric motors are then driven by the charged battery to operate the electric vehicle. Click below to learn more about BEVs.	MG ZS, TATA Nexon, TATA Tigor, Mahindra E20 plus, Hyundai Kona, Mahindra Verito
Plug-in Hybrid Electric Vehicle (PHEV)	HEVS are sometimes called parallel hybrids. A HEVs has an electric motor in addition to the engine. Fuel provides energy for the engine, while batteries provide power for the motor. The electric motor and engine turn the transmission simultaneously. The wheels are then driven by this transmission. Click below to learn more about HEVs.	Engine, Electric motor, Battery pack with controller & inverter, Fuel tank, Control module
Hybrid Electric Vehicle (HEV)	Another name for PHEVs is series hybrids. These vehicles have both a motor and an engine. You can choose between using conventional fuels, such as gasoline, or alternative fuels, such as biodiesel. Also, a rechargeable battery can be used to power it. The battery can be charged outdoors. For more information on PHEVs,	Porsche Cayenne S E-Hybrid, BMW 330e, Porsche Panamera S E-hybrid,
Fuel Cell Electric Vehicle (FCEV)	Another name for FCEVs is Zero Emission Vehicles. To generate the electricity needed to power the car, they use “fuel cell technology”. Electrical energy is generated directly from the chemical energy of the fuel. For more information about FCEVs,	Toyota Mirai, Riversimple Rasa, Hyundai Tucson FCEV, Honda Clarity Fuel Cell, Hyundai Nexo.

Sources : NITI Aayog. (2023).

2.2.3. Types of Electric Vehicles and Their Role in Global Market Adoption

2.2.3.1.Battery Electrics Vehicles (BEVs)

The basic idea of a battery electric vehicle is the vehicle consists of an electric motor, a controller, and an electric battery for energy storage. Plugs and battery charging equipment, which can be placed at charging stations or carried in the car, are typically used to recharge the battery from electrical energy. Usually, the controller controls the power supply of the motor and, consequently, the forward and reverse speed of the vehicle. This is usually referred to as a two-quadrant forward and reverse controller. Usually regenerative braking is used to recover energy and as a practical form of goose-less braking. “If the control allows Regenerative Braking in both the front and rear directions, this is known as 4-quadrant control. Larminie, J., Dicks, A., & McDonald, M. S. (2003).

Battery electric vehicles (BEVs), which continue to show an exponential growth trend, have the potential to drastically reduce greenhouse gas emissions from road transportation worldwide. System-wide adoption is much faster than anticipated by common economic evaluations so far, according to model-based projections for future adoption that take into account historical trends. For example, by 2031 or thereabouts, we expect most passenger cars in Europe to be electric. The date of mass adoption is predicted to be less dependent on model features in different regions. Although current electric fleet numbers vary widely by region, growth trends typically show a rapid doubling period of around 15 months, indicating a drastic infrastructure and economic impact in the near future. Jung, F et al. (2023)

2.2.3.2. Electric Hybrid Vehicle (HEVs)

A car that has two or more energy storage systems in it is called a hybrid. One Type of hybrid electric vehicle is a g asoline-powered car that doubles as a fuel converter. A bi-directional electricity storage device is another type. Hybrid electric vehicles use energy storage in several methods to save fuel consumption, including brake energy recovery, engine downsizing, more efficient engine operation, and engine shutdown when stationary. Chan, C. C., Bouscayrol, A., & Chen, K. (2009).

Regenerative braking, which converts the vehicle's kinetic energy into electrical energy to charge the battery instead of losing it as heat as happens with traditional brakes, is one of the efficiency-enhancing technologies used by modern HEVs. Certain HEV models charge the battery or power its electric drive motor directly by using its internal combustion engine to turn an electric generator (a combination known as a motor-generator). Kebriaei, M., et al. (2015).

In the short term, hybrid electric vehicles (HEVs) can be a good way to achieve global goals for greenhouse gas emissions from road transportation. To encourage HEV adoption, a number of national and international government policies based on taxation or rebates have been implemented. This study evaluates market preferences for electric vehicles in Spain empirically while looking at the impact of subsidies. A representative sample of 1,200 drivers in Spain participated in an interactive online poll. When compared to standard vehicles, drivers were willing to pay €1,645 more for HEV models, which is much less than the selling price of such vehicles, so there may not be much impact on increasing the adoption of this type of vehicle from the level of economic incentives applied in isolation. Overall, it was found that drivers have glaring misconceptions about HEVs, which affects their opinions and decision to purchase. Therefore, to increase demand for HEVs, a mix of policies with different incentives (such as communication campaigns) is required. Rahmani, D., & Loureiro, M. L. (2018).

2.2.3.3.Fuel Cell Electric Vehicle (FCEVs)

The electric motor found in fuel cell electric vehicles (FCEVs) operates using electricity. In contrast to traditional electric vehicles, FCEVs produce electricity through hydrogen-powered fuel cells rather than depending exclusively on batteries. The optimal size of the electric motors, or those utilizing a combination of fuel cells and batteries, is a critical factor that manufacturers consider to determine the vehicle's power output during the design process. Currently, most FCEVs incorporate batteries to enhance the power generated by the fuel cell, deliver additional energy for brief accelerations, and recover energy during braking. Although manufacturers can create FCEVs with plug-in capabilities for battery charging, the majority offer features that allow the fuel cell to idle or switch off when power demands are low. U.S. Department of Energy. (2025).

Adopting FCEVs in the global market requires a systemic approach that considers STEEP factors and involves various stakeholders. The proposed roadmap provides guidance to overcome technological, economic and social barriers, and capitalize on environmental and political opportunities. With the right strategy, FCEVs can become a key solution for sustainable transportation, reducing emissions and improving global energy security. Sokolov, A., Saritas, O., & Meissner, D. (2019).

2.2.3.4. Plug-in Hybrid Electric Vehicle (PHEVs)

The technology known as plug-in hybrid electric vehicles (PHEVs) has the potential to replace most of the fuel oil we use for transportation. HEVs that can use electricity from the power grid to recharge their energy storage systems are known as plug-in hybrids. When the energy storage system is fully charged, the vehicle will prefer to use electricity instead of liquid fuel. The fact that PHEVs are no longer dependent on a single fuel source is one of their main advantages. Electricity generated from various domestic resources, such as coal, natural gas, wind, hydropower, and solar energy, serves as the primary energy carrier. Liquid fuels, such as gasoline, diesel, or ethanol, serve as secondary energy carriers. Markxel, T., & Simpson, A. (2006).

PHEVs play a strategic role in the adoption of new energy vehicles globally thanks to their flexibility, ability to reduce emissions, and ease of integration with existing infrastructure. China's success in promoting PHEVs, supported by strong policies, technological innovation, and evolving infrastructure, provides valuable insights for the global market. By overcoming challenges such as cost, infrastructure, and public perception, PHEVs can serve as a bridge to fully electric transportation, supporting global decarbonization goals. Wang, Z. (2023).

2.2.4. Electric Vehicle (EVs) Market Growth

Electric cars (EVs) are gaining popularity. While transitioning from traditional passenger cars, which have internal combustion engines and use fuel oil, to electric vehicles (EVs), which are four-wheeled vehicles that can be powered fully or partially by electricity, Union of Concerned Scientists. (2015). Electric vehicle sales worldwide remain strong. By 2022, a total of 10.5 million new electric and hybrid electric vehicles will have been delivered, a 55% increase compared to 2021. However, regional growth patterns are changing. In Europe, electric vehicle sales increased only 15% compared to 2021 after two years of sharp increases. The crisis in Ukraine has exacerbated an already poor automotive market overall and ongoing component shortages. Although the overall light vehicle market is poor and fell 8% year-on-year in 2022, sales of electric cars in the US and Canada were up almost half on last year. After a disappointing first half in 2021, the car market has indicated a slight recovery since halfway through 2022. The market for passenger cars and commercial vehicles of up to 6 t GVW reached 81 million units worldwide in 2022, which is 0.5% lower than in 2021 but 15% lower than in 2020 Irle, R. (2023b).

There are currently 50 light-duty electric vehicles offered in the U.S., and foreign manufacturers are investing at least $140 billion in electric vehicle technology ,Moore, J., et al. (2021). From moderate success (~13% of sales in 2050) to complete market dominance (EVs making up 100% of light-duty vehicle sales well before 2050), future estimations of EVs' involvement in LDV markets vary greatly. According to numerous studies, EVs are currently cost-competitive for various applications or may soon catch up to ICEVs in terms of economics. (Kapustin and Grushevenko 2020; Yale E360 2019; Weldon, Morrisey, and O'Mahony 2018; Sioshansi and Webb 2019) Additionally, electric trucks are gaining popularity, and according to Bloomberg New Energy Finance (Bloomberg NEF), alternative fuels will either match or surpass diesel in long-distance uses by 2025. Moore, J. et al. (2021).

Table 2.2. The rapid increase in EV adoption is underpinned by three key pillars:

Key Pillars	Description	Supporting Sources
1. Battery Technology Advancements and Cost Savings	Battery technology advancements and cost savings, first made possible by the widespread use of lithium-ion batteries in consumer devices and smaller automobiles (such as scooters, particularly in China). IEA .(2017). When compared to IEVs, these advancements present EVs and HEVs with increasing and evident potential to provide a lower total cost of ownership.	IEA (2017)
2. Governmental Support and Environmental Policy Tools	Several governmental tools that support clean transportation options in important international markets, which are reflected in private sector investment Axsen et al., (2020). Environmental objectives, such as lowering local air pollution, are the driving force behind these improvements IPCC. (2014). These policy tools encourage the deployment of charging infrastructure (Bedir et al. 2018) and offer both monetary and non-monetary incentives to encourage the adoption of EVs, such as rebates and vehicle registration discounts, as well as access to high-occupancy vehicle lanes and preferred parking (IEA 2018a, AFDC 2020).	Axsen et al. (2020); IPCC (2014); Bedir et al. (2018); IEA (2018a); AFDC (2020)
3. Regulatory Frameworks and Market Mechanisms	Laws and regulations to encourage the adoption of fuel-efficient vehicles and reduce the use of petroleum include low carbon fuel standards, ZEV mandates, and fuel economy standards. These are reinforced through market-based instruments including public procurement policies, intended to enable the deployment of clean mobility technologies, to reduce vehicle prices due to technology learning, economies of production scale, and risk mitigation. Furthermore, technology-push policies mainly involve market-based instruments, such as subsidies, and research and development (R&D) program options that drive low carbon technology innovation, such as new battery technologies.	Muratori et al. (2021)

Sources : Muratori et al. (202

Over time, environmental sustainability and energy conservation have gained more attention and concern on a global scale. The ecosystem has been severely damaged by human activities that produce greenhouse emissions Faizal, M., et al. (2017). Internal combustion engines (ICEs), which use fossil fuels and emit toxic fumes, have been the backbone of the automotive industry for centuries. In the meantime, electric cars, or EVs, have become popular and provide many benefits over cars with internal combustion engines. EVs can potentially lower greenhouse gas emissions, have faster and more efficient acceleration, and use less energy. Marshall, B. M. et al. (2013). One of the biggest sources of damaging pollutants is the transportation industry. Since the world is already moving toward sustainable energy and low-carbon initiatives, the electric mobility (e-mobility) strategy seeks to hasten the switch to cars with low or zero emissions`

Sales of electric vehicles continued to rise, with an increase of 21% in Europe, 87% in China, 55% in North America, and 78% in Non-Triad countries, showing that they can prosper in difficult automotive markets. Global light vehicle sales were slightly down year-on-year (-0.5%), with Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) bucking the trend with volumes up 55%.The lack of growth in EV sales in Europe, however, can be mainly pinned on the 2020-2021 boom and the continued aftershock of the Ukrainian conflict. China accounted for a leading 59% of the global EV market in 2022. It confirmed its position as the world’s leading centre of electric car manufacturing, producing 6.7 million units—a 64% share of global output. Very notably, out of China's nearly 580,000 EV exports, some 407,000 of those were from Western brands. The most significant exporters are Tesla, SAIC, Dacia, Polestar-Volvo, and Lynk & Co.Irle, R. (2023d).

Analysis of Electric Vehicle Index EVI performance over time shows that China has rapidly surpassed the United States and Germany in aggregate EVI scores. Figure 3 illustrates that China and Germany were nearly tied in 2014. By 2018, China had significantly surpassed Germany in both market and industry EVI scores. China improved its market EVI score through increased EV sales, substantial monetary and non-monetary incentives, greater model diversity, and significant investment in charging infrastructure. China leads in industry scores, significantly increasing EV manufacturing and component share. Significant restrictions on domestic content—especially sanctioned battery manufacturers—limit China’s EV profit pool primarily to local entities. Hertzke, P., et al. (2018).

Stellates increased its EV sector share in the USA and Europe, but it was unable to take advantage of China's rapid expansion due to its limited presence there. Compared to many other western OEMs, the +34% volume growth is still superior. In particular, two factors have ignited a new era of transportation: the bold and unlikely ascent of EV manufacturer Tesla . MacDuffie, J. P. (2018), and the rise of China, with its plethora of EV start-ups, as the world's EV hotspot. China, which sees a huge and fresh business opportunity from the shift, accounted for more than half of all EV sales in 2018 and 2019. Kennedy, S. (2018).

Over the past ten years, there has been a push for the use of electric cars (EVs), which are automobiles that run mostly on plug-in power. The electric motor is powered by rechargeable batteries that store electricity from the distribution grid after being plugged into a home charging outlet. Qu, Z., & Zhang, S. (2020). According to Kühnbach, M., et al. (2020). EV sales growth is currently a reality worldwide. However, because of things like high initial costs, battery degradation, or a lack of suitable charging infrastructure, not everyone can currently afford to buy an EV. However, e-mobility has advanced to a point where it cannot be reversed. EV purchases rise as more models become available and prices come down, reaching a larger segment of the population that owns vehicles. By 2025, they will account for over 10% of sales, and by 2030, they will account for 20–30% of sales. Hoover, Z., et al. (2021).

Analysing EVs' anticipated sales growth and weight in the automobile fleet is a prerequisite for conducting a thorough evaluation of their effects on the distribution grid for the 2020–2030 decade. Among other things, the evolution of the population index, current automobiles, selling prices, market supply, and purchase incentives should all be taken into account. We will illustrate the progress of EVs between 2020 and 2030 in three projections due to the difficulties of forecasting all those aspects and their interactions. Nogueira, T,et al. (2021). Based on the available EV data, Projection 1 projects the population's evolution within the specified geographic area. Project 2: By 2030, EVs will make up one-third of all sales. According to Projection 3, 20% of all cars will be electric by 2030. We compute the demographic evolution for the nation and the north area of Portugal as indicated through 2030 in order to bolster those projections. The regional population evolution up to 2030 was calculated using national criteria, municipalities' own evolution, and data gathered from the official PORDATA database and the current Portugal database. IMT (2021). According Palomino,et al. (2021), to calculate the projected sales of EVs until 2030, the required inputs are the anticipated population and the fleet of passenger cars. We can expand on the three above-mentioned estimates for the development of EVs using the results of these earlier computations.

2.2.4. Global EVs Market Growth Trend

New regulations have been put in place to encourage EV market penetration, which has helped explain the current increase in EV sales. Global EV Outlook. (2016). Price reductions and accelerated development of electric vehicle technology are needed to encourage electric vehicles to enter the general market. The main obstacle to the entry of electric vehicles into the market today is their high selling price. Boulanger, A. G, et al. (2011). Global EV sales surpassed one million units in 2017, representing a notable 54% increase over 2016 sales of new EVs. China has the biggest EV market, accounting for almost half of all EV sales worldwide. As can be seen in Figure 1 below, China accounted for 40% of the total sales of EVs in 2017, surpassing 3 million units worldwide. It is also evident that the US has the second-largest EV market. Faizal, M, et al .(2019). Although electricity and oil prices differ globally, driving an electric vehicle is typically cheaper than driving an oil-fueled car. Using average electricity prices and average electric vehicle efficiency, an electric vehicle traveler in the US would spend $7.42 for a 200-mile trip. The cost to drive a regular car is $22.60 (again, assuming average fuel costs and average fuel efficiency). Moreover, unlike the volatile oil market, customers can anticipate that electricity prices will be more stable over time. Olson, C., & Lenzmann, F. (2016).

conventional vehicles, everything must sync up for it to run at its best due to the numerous moving parts, all of which have a limited lifespan. In comparison, electric vehicles (EVs) have far fewer moving parts – as few as twenty-four, perhaps – so the chances of mechanical failure are numerically reduced as well. For instance, EVs include no lubricating oils, filters, clutches, spark plugs, pistons, timing belts, fan belts, water hoses, radiators, or catalytic converters. Homeowners or tenants with EVs can charge their vehicles using the electric system in their home. The capability of fully charging overnight and being ready to go the following morning is a way that EVs can be slotted into life with domestic products. As a result, EV users typically do not have to depend on public commercial charging infrastructure while driving in cities. But just as with traditional cars, long drives will require highway pit stops. Although there are fewer highway charging facilities than gas or diesel refuelling stations, government and industry stakeholders are working to create an infrastructure that would rival and exceed the convenience of today's fuelling choices. International Council on Clean Transportation (2020).

2.2.5. Policy on EVs Adoption

Numerous countries have taken numerous legislative steps to stimulate the creation of the electric vehicle by promoting their production and sale. By 2017, seven leading countries in terms of the number of electric vehicles owned, apart from China, had significantly beneficial instruments for the spread of electric vehicles. The high rate of growth of the electric vehicle sector in these countries is caused mainly by broad tax benefits and subsidies. Thanks to the active position and focus on results of the Norwegian government, electric vehicles accounted for 39% of new cars sold in 2017. These are the most successful ratios across million indicators for each country. Vehicles driven solely by batteries are less expensive than fossil-fired vehicles. For instance, in 2016, the vehicle manufacturer's suggested resource usage for a Volkswagen e-Golf was $32,157 as compared to $33,226 for a base diesel Golf according to Li, J et al. (2019). Analysis of the total cost of ownership of conventional cars, HEVs and BEVs in 14 major US cities shows that federal and state incentives are needed for BEVs to be cost-competitive. This suggests that, even in the most optimistic scenario, BEVs will struggle to achieve the most competitive cost without subsidies. Breetz, H. L., & Salon, D.

(2018). To encourage electric vehicles, the US and EU have implemented long-term efficiency standards along with certain regulatory incentives (ICCT, 2015). To support its efficiency goals and purchase incentives, China has created a credit trading market for electric vehicles (Reuters, 2016). Local governments have also enacted legislation to encourage the adoption of electric vehicles. Electric vehicles are exempt from the quota scheme used in Beijing and Shanghai, where new vehicle licenses must be obtained through a lottery. Electric vehicles are immune to congestion pricing, which has been implemented in other countries such as London. Norway complements its financial incentives for consumers with a network of amenities, such as free access to parking lots, bus lanes and toll roads.

Tariff and subsidy policies have a major impact on the adoption of electric vehicles, as shown by the impact of government financial interventions on competitive models that include both conventional and green supply chains. Hafezalkotob, A. (2015). Governments, manufacturers and consumers are engaged in interactions throughout the electric vehicle deployment process, and various stakeholders work together to shape the growth of the electric vehicle sector. On the other hand, many studies focus on a single issue. Liu, D., & Xiao, B. (2018).shows how national policies, particularly financial policies, affect the market penetration of electric cars in China. This is done by making a scenario analysis based on a system dynamics model to see the development of electric vehicles based on direct and indirect policies. Tian et al. (2014) used a system dynamics model based on evolutionary game theory to examine how the Chinese government, businesses and consumers interact in the deployment of green supply chain management of EVs. Their findings suggest that incentives for manufacturers, rather than consumers, may be more successful in driving the deployment of green supply chain management practices, such as those involving electric cars.

2.2.5.1. The Role of Government Policy in Driving EVs Growth

The government provides financial incentives to buyers of electric vehicles in various ways. Subsidies, such as income tax breaks and car purchase rebates, and vehicle tax breaks, such as annual and one-time tax breaks, are two common categories of incentives. Other countries examined in this study provide car tax breaks (Norway, Netherlands), others provide subsidies (United States, British Columbia, Quebec, Ontario), and some provide both (United Kingdom, Germany, China). In general, consumers and electric vehicle models differ in terms of the monetary value of the incentives provided. Slowik, P., & Lutsey, N. (2016 a)The energy industry and macroeconomic system can be greatly affected by a shift to an environmentally friendly transportation sector that uses efficient engines and alternative fuels. Alternative fuel vehicles (AFVs) can be promoted through the implementation of supportive measures such as scale incentives, provision of fuel infrastructure, restrictive/regulatory methods, and marketing initiatives, in addition to potential technological advancements. Adoption and usage patterns of green vehicles are largely influenced by fuel and vehicle scale incentives, including subsidies and tax levies. Shafiei, E, et al .(2018).

Financial incentives can help electric vehicles overcome the high costs of these early years and move closer to cost parity with traditional cars. Consumer education and awareness campaigns and the expansion of charging infrastructure will remain important. Regulations related to carbon emissions and fuel economy will be important in promoting electric vehicles to the mass market from 2025. Slowik, P., & Lutsey, N. (2016 b). Electric vehicle sales in North America are being eclipsed by the rapid expansion of the European and Asian markets. Most electric vehicle sales in these three regions occur in markets where buyers have a large financial incentive to purchase. More than 90% of global electric vehicle sales come from nine national vehicle markets in these three regions. Lutsey, N. (2015).

2.2.5.2. Impact of Fiscal Incentives on Electric Vehicle Growth

To help them reduce oil consumption and meet air quality and climate change mitigation goals, many governments at all levels - national, provincial, state and local - are providing financial incentives and other regulations to encourage electric vehicles. To encourage the growth of domestic industry leaders in emerging technologies, the government also provides assistance to electric vehicle technology businesses. The government often provides financial assistance and policy support to the nascent electric vehicle sector to encourage manufacturing, research and development, and infrastructure for electric vehicle charging. Nealer, R. (2022).

To encourage wider use of electric vehicles, governments in developing countries that market electric vehicles are gradually implementing more direct regulations. For example, ten states in the United States have implemented Zero Emission Vehicle (ZEV) regulations, which require that by 2025, 15% of new cars sold must be electric vehicles. Yang, Z, et al. (2016).

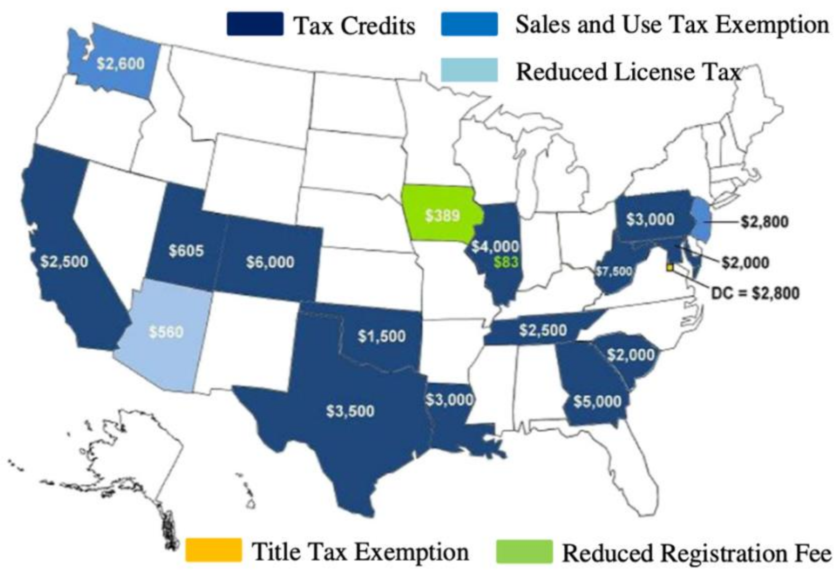


Figure 2.2. indicate 18 US states offer tax credit incentives

Sources : Zhou, Y., et al. (2015).

Several other states provide additional incentives, based on “toll credits,” “tax credits,” “exemptions” for HOV lanes, or reduced fees, as demonstrated in Figure 2.11. On the top end, West Virginia and Colorado offer the greatest reward, offering tax credits of $7,600 and $6,000, respectively. In some regions, utilities also offer reduced electricity rates to establish a dedicated meter to charge your PEV. According to data firm R.L. Polk & Company, which offers data services in automotive industry analysis, 54% of the country’s plug-in electric vehicles (PEVs) are located in just five cities: Atlanta, Los Angeles, New York, San Francisco, and Seattle. Zhou, Y., et al. (2015).

2.2.6. Infrastructure on EVs Growth

Weighing the advantages and disadvantages of public charging infrastructure and estimating its impact on future electric vehicle sales requires estimating its value to current and future electric vehicle owners. Achtnicht, , et al. (2012). Increasing the market share of electric vehicles is necessary to highlight the continuous progress in charging technology. The “chicken or egg” notion is now a barrier to widespread adoption of electric vehicles. Greene, D. L, et al (2020a).Electric vehicle charging stations should be placed in strategic areas to provide affordable and clean electricity generated by the grid and renewable energy sources. Choice of acceleration head for electric cars. Alhazmi, Y. A, et al. (2017). By creating a sufficient network of charging stations, electric vehicle owners will have less to worry about and EVs will be able to compete with internal combustion engines in terms of performance. Clemente, M, et al (2014). Customers are eagerly awaiting a suitable charging infrastructure that ensures a successful commute with little or no charging time delays. As a result, investors are delaying investment in charging infrastructure until there are enough electric cars on the road. As to whether smart charging or fast charging is more appropriate for EV charging stations, stakeholders cannot agree. Government policies also have. Wolbertus, R., Jansen, S., & Kroesen, M. (2020).

2.2.6.1. Relationship between Charging Station Availability and EVs Adoption

Electric vehicle is a hot topic for the recent years. The improvement of EV charging infrastructure and the changes both on technical requirements for electric vehicles (EV) and network management have been analysed in many works. One key factor in increased use of electric vehicles for day-to-day trips is an adequate system of charging infrastructure. Such infrastructure can increase the visibility and legitimation of electric vehicles, encouraging even greater adoption.If at least home or workplace charging is not an option, you may want to consider and feel for public charging of Electric Vehicles. Furthermore, public charging infrastructure is very important to reach a widespread adoption of electric vehicles (Bailey, J., Miele; Funke, S. Á., Gnann, et al., 2015). The lifestyle hypothesis explains the different ways customers perceive public charging infrastructure and Plug-in Electric

Vehicle (PEV) technology. For example, customers who value environmental sustainability will consider PEVs and charging stations as a way to reduce the number of cars on the road, which will be good for the environment. Conversely, tech-savvy consumers may see the use of PEVs and charging infrastructure as a way to gain access to the latest technology and may be more interested in controlled charging schemes that improve grid efficiency. Axsen, et al. (2018).

In the context of EV charging, charging can occur at various locations such as public CHSs, homes, or workplaces for agents. The possible primitive behaviours in the scenario are described as follows: Agents recharge their EVs in the following times. If a charging infrastructure is installed at the end of the trips and the recharge level is less than the consumed energy, the agent will charge his/her vehicle at recharging and will continue with the relevant trip. It should be noted that PHEVs are relatively less likely to need public charging stations because they can rely on gasoline engines for power, and as a result, we only model BEV owners who use public charging stations Adepetu, A., & Keshav, S. (2017).

Electric vehicle charging opportunities are directly linked to the owner's traveling habits. The following are examples of strategic locations for electric car charging: (1) in or near homes; (2) workplaces or frequently visited travel destinations; (3) places open to the public, including supermarkets and shopping malls; and (4) rest stops along important highways for long-distance trips. Haryadi, F. N., et al .(2023).The most important element in attracting customers to purchase Plug-in Electric Vehicles (PEVs) is the availability of charging at home. Skippon, S., & Garwood, M. (2011).

2.2.6.2. Impact of “Range Anxiety” on EVs Purchase Decision

The battery electric vehicle (BEV) has attracted public interest recently. One of the popular subjects in conversations and news is the so-called “range anxiety.” Aims and Objectives: Almasy, S. (2010) reported that range anxiety for mileage might hinder the extensive use of BEVs. Several factors that influence user experiences in relation to mileage anxiety have been identified in Luettringhaus, H., & Nilsson, M. (2012), i.e., Individual differences (e.g., personality traits, trust in the functionality of BEVs), System characteristics (e.g., support by assistance systems and advanced information technology, existent fast charging stations while on the road), Environmental elements (i.e., time of day (day vs. night) or geographical context (urban vs. rural areas) Rauh, N., Franke, T., & Krems, J. F., (2015).Public charging infrastructure has both material and immaterial benefits, such as reducing 'range anxiety' and increasing optimism about the future of the electric vehicle market. Analyzing the value of public charging infrastructure can help forecast how charging infrastructure will affect future electric vehicle sales and guide investment decisions. Greene, D. L, et al (2020b).

2.2.7. Theory Application

2.2.7.1.Diffusion of Innovation (DOI) Theory

DOI theory stresses believed technology characteristics and innovative characteristics of the adopting unit. According to Rogers, E.M. (2003a), there are five characteristics of innovations that influence the potential for acceptance: 1)Relative advantage over existing technologies,2) Compatibility with existing workflows and organization-specific knowledge, 3)Complexity of implementation,4) Trialability, 5)Observability of the innovation (both internally and in terms of competitors).The more that an individual rates all up to five in the following, the more they are open to innovating.

Rogers's (2003b) model of the innovation decision-making process based on the stages of adoption was also applied, which is mainly characterized by seeking and processing information that can reduce the uncertainty regarding the pros and cons of a specific invention. This transition begins with awareness of an innovation, leading to attitude formation toward the innovation, a decision to adopt or reject the innovation, the adoption or rejection of the innovation, and the confirmation of this decision. These stages involve cognition, persuasion, decision, implementation, and confirmation, as described by Rogers. During the knowledge phase, people involved want to understand what an innovation is and how it works. In the persuasion and decision phase, they gather additional information to assess the innovation and minimize uncertainty about expected outcomes. The concluding phase results in either accepting the innovation as a preferred action or deciding not to do so. Reinvention refers to how substantially the innovation is adapted or revised during this phase.

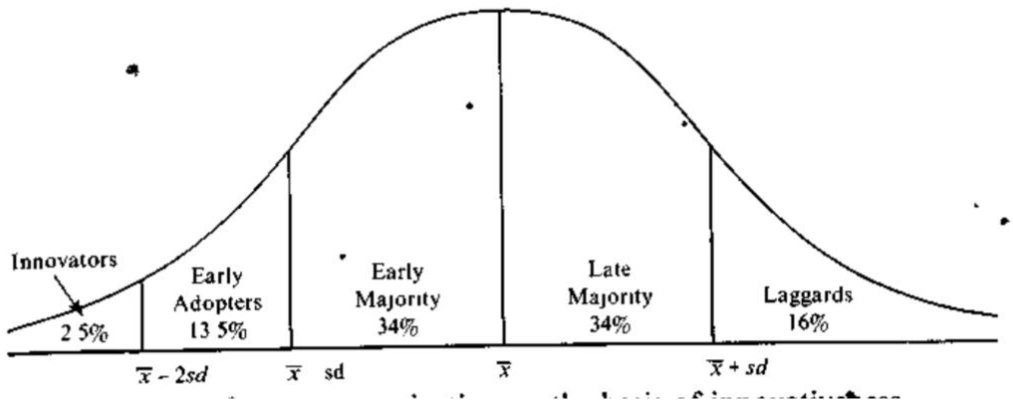


Figure.2.3. Adopter Categorization on the basis of Innovativeness

Sources : Rogers,E.M.(1997a).

The Innovation Dimension is determined through measuring when the adoption of an innovation occurred and defined as interval variable. However, by excluding the standard deviation of average adoption period, such dimension can be reclassified into five segments of adopter. Much of the research emanating from diffusion studies has been organized around factors that relate to innovation, and in this narrative, we will crystallize these within a few macro categories and subcategories such as: 1) social class, 2)innovator characteristics, 3) communication behavioural characteristics. Rogers, E.M. (1997b).

Table.2.3. The characteristics of innovations, as perceived by individuals, help to explain their different rate of adoption.

Relative advantage	The extent to which new ideas are accepted as better than what they replace is important. Even if the relative benefits may be evaluated economically, other issues such as social status, convenience, and preference to use often play a major role as well. The added value of the quantifiable "objective" advantages of an innovation tends to be limited. What matters is indeed the subjective judgment of whether an invention is useful. Higher perception of relative advantage results in faster adoption of innovation as a rule.
Compatibility	The extent to which an innovation is perceived as consistent with the existing values, prior experiences, and needs of potential adopters will determine the rate of adoption. Novelty that competes with the dominant values and beliefs in a culture will tend to be adopted more slowly than novelty that is consistent with them. Adopting a new practice that does not fit in will thus typically require us to form over values sans delay. A high-profile example of an incompatible innovation would be the adoption of contraceptives in cultures whose religious beliefs are against birth control, such as Muslim and Catholic countries.
Complexity	The relative difficulty of understanding and using an innovation is not in a straightforward manner. Some innovations are easier for most people in a social system to understand than others, which results in a faster or slower rate of adoption. Los Molinos; they were unacquainted with the fermentation theory. Health workers were retorted with the germs everyone sees them. We cannot be told that germs are dangerous for the annals of breeding habits. Modalities of bubonic plague transmission. It's easy to understand that simple ideas are faster to be implemented over complex ones.
Trialability	Applicableness in small scale makes an idea acceptable. Anything that can bring instalment good terms is likely to penetrate more rapidly than if it does not allow spreading type. Ryan and Gross (1943) found that every farmer they surveyed who used the new hybrid seed corn in Iowa first

	experimented with it in small acreage before expanding to full-scale use. Had the test run down here not been available, the adoption of the new seed would have been much less.
Observability	The visibility of innovations has been suggested to be one of the factors affecting its adoption. When people can more easily see the fruits of the innovation, they are more likely to accept it. This exposure leads to conversations among friends about the new idea, as friends and neighbours who see others take it up ask about the experience. For example, solar arrays located on building rooftops are highly visible; in California, a study showed that the typical owner of a solar electric system exhibited their system to about six people (Rogers et al., 1979).

Sources: Rogers,E.M.(1997c

Schuitema et al. (2013) related the intention toward acquiring EVs with consumer innovativeness, which is a consumer's tendency to be among the first adopters concerning new products (Foxall et al., 1998 in Schuitema et al., 2013). They found three motivational dimensions underlying consumer innovativeness: instrumental rewards, hedonic rewards, and symbolic rewards, originating from the theoretical framework of Andecasteele, B., & Geuens, M. (2010). Instrumental reasons consider the functioning of the car. In contrast, hedonic motivations emphasize expected emotional states, such as the enjoyment stemming from the driving task. Finally, symbolic motives are about the importance of symbolic properties of a car for the buyer (Schuitema et al., 2013).

DOI model has been commonly utilized to examine the way by which early and potential adopters perceive the innovation's attributes, including those on environmentalism.However, although many of DOI studies tend to ignore this aspect, paying special attention to recent research on innovation adoption, the role of emotions becomes a key element. Preliminary results reveal that it is crucial to consider consumers' emotions to understand this domain. Only the woods and a rippling brook adding its melody to the rustling crunch of underbrush beneath each foot. It is fresh, and the air is clean over this property, scents of musk fill my nostrils. The cool night has the strange amount of dew and blooming wildflowers. And upon the carpet of dead leaves, which the consummate shade bewitched into a mass of obscurity, the sun pours a gentle and cheering light, so that we see the feathery ferns and tufted mosses, which flourished under the canopy. (Wood, S. L., & Moreau, C. P. (2006).; Watson, L., & Spence, M. T. (2007).; Shih, E., & Schau, H. J. 2011). For example, a study by Shih, E., and Schau, H. J. (2011) investigated how consumers' expectations about future scenarios and the subsequent emotions that arise can affect their adoption behaviors. The researchers found that perceived innovativeness—consumers' perception of changes in technological progress, that is—can contribute to anticipated regret, which, in return, might delay their purchase of new technologies (Shih, E., & Schau, H. J., 2011b). Also, Wood, S. L., and Moreau, C. P. (2006) revealed that complexity perceptions about technological innovations moderate emotions that affect evaluations of innovations as well as post-adoption purchase behavior. Building on these findings on emotional influences on the adoption of innovation, emotional aspects associated with the acceptance of EVs deserve to be considered.

2.2.7.1.Theory of Planed Behaviour

The Theory of Planned Behaviour (TPB) posits that individuals make decisions based on reason and assess stimuli and outcomes (consequences) Ajzen, (1991). Intention is a main predictor of behaviour. Consumer perceptions are those perceptions of an act's general potential positive and negative consequences; these are predictors of intent Bamberg & Möser, (2007). According to the TPB model, intention is affected by PBC and expectations from or specific reference groups or subjective SNs as well as attitudes. Social norms theory posits that the more consumers come to consider that behaviour as socially accepted, the more they are likely to intend to perform that behaviour Ajzen, (1991).

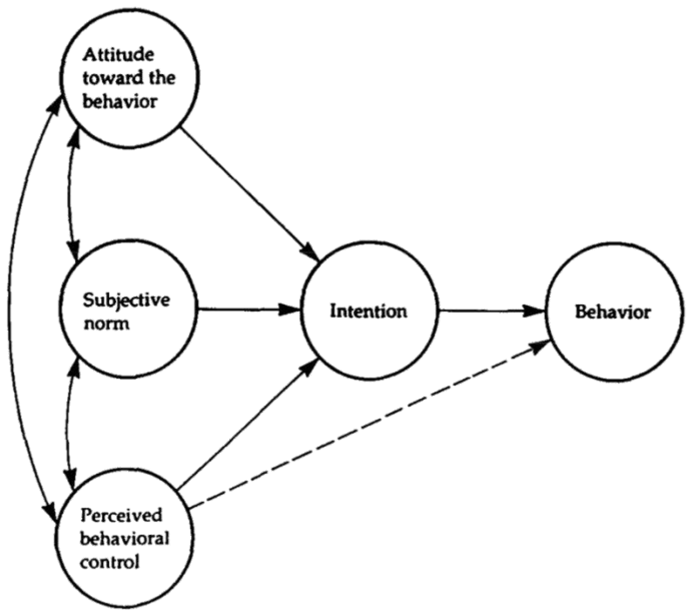


Figure.2.4. Theory of Planed Behaviour

Sources : Ajzen, I. (2002).

Theory of Planned Behaviour (TPB) has been used in a number of studies to explore and predict consumer acceptance of cleaner vehicles by consumers (Lane, B., & Potter, S. (2007); Moons, I., & De Pelsmacker, P. (2012)). In research about consumer acceptance of Electric Vehicles, acceptance attitudes toward electric vehicles were studied, considering not only general EV consideration but also purchase price, range, and maintenance required of EVs. Within the framework of TPB, attitudes reflect the degree of favourable or unfavourable appraisal of the positive and negative consequences of performing a behavior; however, in the context of its application to innovation adoption, greater emphasis has been placed on attitudes toward the innovation itself. (Pickett-Baker, J., & Ozaki, R. (2008, Moons, I., & De Pelsmacker, P. (2012), Egbue, O., & Long, S. (2012).

Perceived knowledge and personal experiences as a part of the Theory of Planned Behaviour (TPB) framework are critical because they have an impact on attitudes and perceived behavioural control (BC). An easy one is attitude towards electric vehicles (EVs), and it captures consumers' environmental perceptions and concerns, general knowledge, and experiences about driving and being an EV user. In addition, consumer understanding of the costs associated with owning and operating a conventional internal combustion engine (ICE) vehicle versus an EV has been found to be an important element of their beliefs and intentions. (Lane, B., & Potter, S. (2007), Sovacool, B. K., & Hirsh, R. F. (2009).

Similar to the Theory of Planned Behaviour, which states that consumer behaviour is based on rational assessment of outcomes, rational choice theory states that maximizing benefits and utilities underlies human behaviour. Many researchers in the field of consumer electric vehicle adoption consider consumer behaviour in this context to be largely rational, using various aspects to assess consumer attitudes towards electric vehicles to predict purchase intentions. Carley, S., et al .(2013).

2.2.7.3. Institutional Theory

The Institutional Theory of Organizations focuses on institutions in explaining the structure and behaviour of organizations. Organizations are on-the-ground refractions of larger institutional architectures. Institutions are systems of widely accepted ideas, rules, and norms that shape the development and diffusion of organizational forms, design characteristics, and practices. Compliance with rules is seen as a method to provide legitimacy, reduce uncertainty, and increase transparency in an organization's actions and operations. The growing prevalence of institutionalism within organizational analysis reflects a wider dissatisfaction with theories of the organization that reduce it to a matter of efficiency. Organizations do not exist in a vacuum; they must meet external influences such as cultural differences, legal aspects, certain standards and customs, as well as different demands of many stakeholders to be met such as suppliers and clients, government, NGOs, and trade unions. From this perspective, losing weight is not the only matter of business, is always vulnerable to community redefinition. Evolving ideas, regulations, and expectations explain decisions within formal frameworks and organizational procedures (e.g., ISO standards, information technology, CSR criteria, or divisional hierarchies). This concept is interesting because it explains the reason for uniformity in design attributes and practices across companies. DiMaggio P, Powell W .(1983)

Institutional theory, or institutionalism, shows the influence of institutions that constrain and enable human activity. Institutions cannot be defined uniformly, as different institutional frameworks offer different definitions Knill, C., & Tosun, J. (2020). Institutions can be understood as a set of legal rules that can be enforced by state actors, referred to as the 'rules of the political game' This concept contrasts with sociological perspectives that view institutions as a synthesis of informal cultural practices and formal rules Hall, P. A., & Taylor, R. C. (1996).Institutions are defined as structures characterized by values, conventions, and customs, which are governed not by central rules but by organizational principles.

According Liu, M., et al, (2024). There have developed an innovation based on Scott's institutional theory to formulate our own theoretical model. This study examines the influence of consumers' use of shared electric vehicles through the lens of regulation, norms, and cultural cognition, which offers a new perspective on sharing economy behaviour and extends the application of Scott's institutional theory. In addition, we confirm that consumers' intention to use shared electric vehicles is influenced by ownership prestige, personal innovation, subjective norms, and government policies through attitudes, while subjective norms also have a direct influence on the intention to use shared electric vehicles.

2.2.8. Socio-Economics Factor

2.2.8.1.Environmental Awareness on EVs Adoption

The mindset that combines environmental concerns, solutions, strategies, and concepts to address environmental issues is known as environmental awareness. Wang, S., et al. (2016).Reducing CO2 emissions and other global warming-causing elements is a top global priority. Every country is working hard to meet this challenge. If people have enough information about the consequences of this problem, they can play an important role individually. According to research, those who have enough information about the environment choose to reduce global warming. Paul, J., et al. (2016).Electric vehicles, are vehicles that perform very well in terms of the environment and emit little or no air pollution. Although some countries have made efforts to promote electric vehicles, the trend of sales volume differs from country to country. In 2015, the United States could not install one million plug-in electric cars (PEVs). Shepardson, D., & Woodall, B. (2016).

According to a recent study, transportation-related CO2 emissions in China will peak in 2039, while emissions will reach saturation point in 2035 and 2043, respectively under sustainable development and rapid growth scenarios. China faces a lot of pressure to reduce carbon emissions from the transportation sector, but legislative reforms could help accelerate those peak years. Wang, W., & Wang, J. (2021). Since electric vehicles do not have the conventional problems of ICEVs such as vibration, noise, or dust emissions, automakers are starting to market them. For countries dealing with power generation, global warming, ecological sustainability, and restructuring of the automotive industry, the promotion of electric vehicles is an important turning point. Cornell, R. (2019).

As a result, the majority of car-producing countries have made national electric vehicle promotion plans to address issues such as energy shortages and pollution due to the increasing number of cars. Despite these advantages, the adoption rate of electric vehicles is still low in many countries, and the full impact of reducing pollution and energy shortages has yet to be realized. Electric vehicles have not been widely adopted in early markets due to various factors including high purchase cost, short range, long charging time, and lack of infrastructure for charging stations. Tarei, P. K., Chand, P., & Gupta, H. (2021). When the Chinese government significantly reduced its incentives for electric vehicles, sales of these vehicles declined. The researchers also recommend that the Chinese government reevaluate its green policies and attract foreign investors to contribute significantly to environmental quality. Xu, G., et al. (2020).These considerations can make the growth of the electric vehicle market problematic. One of the key elements that can influence a person to choose an electric car is environmental awareness. Politicians often make a distinction between sociological and technological issues. Sovacool, B. K. (2018).

2.2.8.1. The role of Environmental Performance (EPI) Score on EVs Demand

The UN has adopted a set of goals to ensure a sustainable world as a result of recent global awareness of environmental and social degradation. Through national plans and roadmaps, countries have pledged to achieve the sustainable development goals (SDGs), underscoring the critical role played by governments in the establishment and successful implementation of related efforts. Governments' inability to create long-term strategies for sustainable development, their financial inability to invest in sustainability, lack of effective technology transfer systems, or trade barriers have been cited as reasons why countries fail to implement the SDGs. Sarvajayakesavalu, S. (2015). Governments also need indicators to track the achievement of these goals. Several studies have proposed metrics and approaches that take into account the environmental, economic and social aspects of sustainability. Cagno, E., et al. (2019).

The "social" constraints to the growth of electric vehicles may be more substantial than the "technical" constraints. In addition to these concerns, it is important to inform the public and determine whether they sufficiently understand environmental changes. Researchers found that elements such as self-identification can influence how customers make decisions. McLeay, F., et al. (2022). Consumers seek to describe their behaviour through their activities, and personality qualities such as self-identification also influence their decision-making. In addition, consumers who care about the environment strive to contribute to the development and improvement of ecological systems. Mustafa, S.,et al. (2022)

2.2.8.2.Relationship between Pollution Level and EV Adoption

Electricity-based fuels do not produce on-road vehicle exhaust emissions, so battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are frequently referred to as zero-emission vehicles (ZEVs). We asked ourselves the question if local air pollution—current due to increased levels of PM2.5 sources, as EVs are advertised as a cleaner alternative to ICEVs.. O'Dell, K., et al. (2021). Depending on the individual PHEV/BEV models, exhaust gas emissions can be fully eliminated or at least significantly reduced. The degree to which EVs reduce air pollution, including greenhouse gases (GHGs), depends on several factors: from the fuel mix used for electricity generation, the battery capacity and weight of the vehicle, to the characteristics of the internal combustion engine vehicle (ICEV) that the EV is displacing. At least three modelling studies have shown that a large expansion of EVs can provide a sizable public health benefit by reducing several forms of local air pollution. Brady, J., & O'Mahony, M. (2011).

Findings by Bayham, J., et al. (2022). show that, shifts in consumer sales of new electric vehicles are related to variations in local air pollution in American cities, with interesting differences between BEVs and PHEVs. First, increased BEV adoption and decreased PHEV adoption are associated with increased PM2.5 air pollution in metropolitan areas. Between 2011 and 2018, the average decrease in PM2.5 air pollution in the 427 metropolitan cities in our sample was 19 percent. Accordingly, the 2010s saw a relative decline in BEV adoption and an increase in PHEV adoption due to reduced air pollution in metropolitan areas. Second, we demonstrate that although the demand for electric cars depends on within-city smog pollution dynamics, its effect is small compared to the effect of PM2.5 pollution. Advantages to electric transportation systems are greatly enhanced by the decrease in air pollution from stationary sources. This suggests that emissions of PM2.5 pollution in relation to the U.S. and electric vehicles should note that overall benefits may be overstated. There is some evidence that the first electric-vehicle adopters will be converts from old-fashioned gasoline or diesel vehicles to new-generation hybrids.. Xing, J., Leard, B., & Li, S. (2021).

Camposeco-Negrete, C. (2013) has examined this issue in relation to the electric vehicle market in China. Using panel data, they show that electric vehicle purchases in 20 major Chinese cities are positively correlated with average PM2.5 concentration levels. They measured changes in local air quality conditions using PM2.5 data, as we did.Various survey-based studies have been conducted to investigate the effects of knowledge, attitudes, and symbolic environmental cues—including climate change fears—on the decision to purchase a battery electric vehicle (EV) over an internal combustion engine vehicle (ICEV). In the early years after EVs began to hit the market in 2010, one survey found early adopters were mostly interested in issues around lowering pollution, saving the environment, and not relying on so much oil. . (Carley et al. 2013; Hackbarth and Madlener 2013; Hidrue et al.2011; Zhang, Yu, and Zhou 2011)

2.2.8.2.Per Capita Income on EVs Adoption

Social and economic inequality is exacerbated by today's private vehicle-dominated transportation system. After housing costs, transportation accounts for the second largest share of household expenditure, and because fixed costs dominate, owning a car is a particularly heavy burden for low-income households. Klein, N. J., & Smart, M. J. (2017). The fact that many electric car models available in 2020 are premium cars contributes to the adoption gap by income. According to zip code-level vehicle registration statistics through 2019, the top 20% of zip codes by income had a 15 times greater Tesla adoption rate as a percentage of all family vehicles than the worst 20% of zip codes by income. The Nissan Leaf was adopted 5.7 times more often in high-income zip codes compared to low-income zip codes, the Chevrolet Bolt 4.3 times more often, the Chevrolet Volt three times more often, and gasoline new cars about twice as often. Atlas EV Hub. (2020).

2.2.8.2.1. Relationship between Income Level and Ability to Purchase EVs

Electric vehicles may become more attractive to low-income people as the electric vehicle industry in the US continues to expand over time, especially for used cars. As of September 2020, the total number of electric vehicles sold in the US was about 1.6 million. Atlas EV Hub. (2020b). Given that low-income households tend to benefit the most from EVs but are typically less likely to adopt them, there is a good argument for directing purchase incentives to low-income consumers. Because lower-income households tend to benefit most from electric vehicles (EVs) yet are less likely to adopt them, there is a legitimate reason for pursuing purchase incentives on behalf of lower-income consumers. Previous research suggested that these incentives had changed considerably over time, and low-income individuals considering EVs had more favorable attitudes towards such incentives.(Jenn et al., 2020; Muehlegger & Rapson, 2018). Setting and incrementally improving income-based eligibility standards may offer an opportunity, especially as EVs become more mainstream and as governments contemplate changes to their incentive programs. Jenn et al., (2020).

Maryland has some of the wealthiest counties in the country. As a result, it is possible that this variable represents the geographic distribution of high-income earners. The price and range of electric vehicles, the amount of income tax deduction associated with the purchase, the range of gasoline vehicles, and ATT_PROEV1, which indicates the respondent's level of agreement with the statement, came next. Electric vehicles should be an important part of our transportation system. Similar circumstances can be found in Sweden and Denmark, and it is no coincidence that these countries have high levels of environmental awareness and average incomes compared to other European countries. When it comes to the adoption of this technology in Sweden and Denmark, this shows the importance of specific car quality, income, and user attitudes towards EVs and the environment. These results are also supported. Glerum, A., et al. (2014).

2.2.9. Fuel Price on EVs Growth

Internal combustion engine (ICE) vehicles are becoming more expensive to operate as fuel costs rise, making electric vehicles more attractive from an economic standpoint. If the price difference between electricity and gasoline/diesel is large enough, consumers tend to see electric vehicles as a more affordable option. By shortening the payback period for the higher initial cost of electric vehicles, rising fuel prices may accelerate the demise of electric vehicles. International Energy Agency (IEA). (2021). The purchase price, maintenance, and running costs of the car are all included in the total cost of ownership, or TCO. While EVs have lower energy costs per mile, the operating costs of ICE vehicles increase in response to rising gas prices. According to the study, the TCO of EVs is equal to or even lower than ICE vehicles in areas with high gas prices, which encourages adoption. Bloomberg NEF. (2022). Fuel prices have different impacts on the growth of electric vehicles in different regions. Due to the large cost difference between gasoline and electricity, electric vehicle adoption rates are much higher in countries with high fuel taxes (such as Norway and the Netherlands). On the other hand, electric vehicle growth is slower in regions with subsidized gasoline prices, such as some oil-producing countries. International Council on Clean Transportation (ICCT). (2020).

2.2.9.1. Impact of Gasoline Price Increase on EVs Adoption

Are electric vehicle customers making judgments based on the assumption that they will fully internalize future power operating costs? Although some recent studies have shown that conventional vehicle consumers (more or less) correctly consider fuel efficiency. Busse, M., et al. (2013).In the context of gasoline vehicles, where consumers are well aware of the relationship between gasoline prices and vehicle usage. In contrast, consumers' experience with electricity is different, and it may be less clear how car usage, home charging, and electricity bills are related. Leard, B., et al. (2023).EV charging, EV driving, and EV purchasing. In general, we rely on extensive surveys, large data sets, and published values for environmental factors such as gasoline prices and EV battery capacity in an effort to make agent behavior as realistic as possible. Adepetu, A., & Keshav, S. (2017b).

Fuel price is an important factor for potential EV car buyers, according to the literature on conventional cars. In theory, fuel economy badges on all new passenger cars, fuel economy calculators, and marketing materials from electric car manufacturers point to differences in fuel efficiency between vehicles. However, there is also reason to believe that consumers are less affected by electricity prices than gas prices. This opinion is supported by two recent articles. Leard, B., Linn, J., & Zhou, Y. C. (2023). In the context of gasoline vehicles, where consumers are experienced in the relationship between gasoline prices and vehicle usage. The consumer experience with electricity is different, and it may not be as clear how vehicle usage, home charging, and electricity bills are related. Gillingham, K. T., et al. (2021).

2.2.9. Population on Electric Vehicle Adoption

Previous studies identified that acceptance of EVs can be influenced by several factors such as context, traits of consumers, and technological developments. The impacts of these go beyond individual consumer attributes and can include regulations, the energy content mix, population density, the power supply infrastructure, and the cost of electricity and gasoline. According to Brückmann, G., Willibald, F., & Blanco, V. (2021), the consumers' willingness to adopt electric vehicles and the required infrastructure to supply such vehicles depend greatly on demographic factors. The subsequent discussion will detail how demographic aspects contribute to electric vehicle uptake, backed by credible data and sources from the IEA (2020). Additionally, the demographic characterization, both in the age distribution and educational attainment, as well as the cultural perception, can also impact the acceptance of electric mobility. Cheaper neither means safer nor cleaner. The research shows the youngest and the most educated are most interested in the environment and more likely to adopt cutting-edge technologies such as e-vehicles (Eizvani, Z., Jansson, J., & Bodin, J. (2015)).

According to Archsmith, J., et al. (2022). To reduce the initial cost differential between electric cars and conventional vehicles, California, for example, offers significant state-level incentives in addition to federal incentives, which has helped maintain the state's rapid electric car adoption rate. Moreover, even without subsidies, Californians may be more inclined to buy electric cars. The state's population is liberal, relatively wealthy and climate-conscious. Sedans, which offer a range of electric-powered options, are relatively preferred by drivers in the state over light trucks, which currently have little EV potential. States that have more rural populations, offer few additional EV incentives, or have people who are less environmentally conscious and more likely to buy light trucks have lower adoption rates.

2.2.10. Urbanization on Electric Vehicle Adoption

According Kiss, J. T., et al. (2025), in their research title “Influence of human capital, urbanization, fuel imports and other macroeconomic factors on electric vehicle adoption” The findings show that while fuel imports have a large negative impact on electric vehicle use, human capital, household savings and urbanization have significant positive impacts. Human capital and urbanization have the largest impact. Electric vehicle use can benefit from reduced dependence on petroleum imports. Electric vehicle use can also have an indirect positive impact through policies that encourage investment in human capital and by spreading knowledge about the environmental impact of electric vehicles.

Li, X., Chen, P., & Wang, X. (2017). According to their study titled “Impacts of Renewables and Socio-Economic Factors on Electric Vehicle Demands – Panel Data Studies Across 14 Countries,” the scope of macroeconomic studies, a subset of economic studies, is limited to analyzing what supports or inhibits electric vehicle market demand. This includes variables such as GDP, urbanization rates, renewable energy production, financial incentives for buying, unemployment, and the presence of charging infrastructure across a set of countries, or clusters of countries, with a range of methodologies.

2.2.11. Previous Study

2.2.11.1. Policy effect on Electric Vehicle Adoption

In the research of Langbroek, J. H., et al. (2016). entitled "The effect of policy incentives on electric vehicle adoption" A lot of countries establish incentive schemes to make AT more attractive. We examine various strategies for introducing potential policy incentives that can stimulate EV adoption and the role of socio-psychological factors in stimulating the widespread EV adoption. It refers to using the Transtheoretical Change Model (TTM) and Protection Motivation Theory (PMT) on stated preferences gathered in a choice experiment. The results point out that policy incentives, in general, increase the probability of EV adoption in the choice experiment as it is anticipated to decrease EV purchase costs in sum. The relatively high value placed on free parking or bus-lane access makes provisions like this a cost-effective substitute for higher subsidy levels. In addition, individuals in later stages of the behavior change process exhibit a higher willingness to use EVs.

Meanwhile, research conducted by Broadbent, G. H., Drozdzewski, D., & Metternicht, G. (2018). In their research entitled "Electric vehicle adoption: An analysis of best practice and pitfalls for policy making from experiences of Europe and the US "This paper provides a conceptual model for policymakers regarding how to increase rates of EV adoption. It particularly emphasizes the importance of financial and non-financial incentives in this shift towards this movement. Results suggest that the impact of these incentives is not uniform and potentially that the presence of a strong charging infrastructure is a key lever on electric vehicle adoption by addressing one of the key drivers and vehicles' limitations. To be able to successfully accelerate the transfer to electric-powered vehicles, there are useful hints, such as: legislative measures, the creation and maintenance of proper public charging stations, government procurement plans, and investments in educational programs to support the transition to fossil fuel-powered vehicles. This paper describes how these tactics can directly impact global adoption rates.

2.2.11.2. Infrastructure effect on Electric Vehicle Adoption

In the research of He, S. Y., Sun, K. K., & Luo, S. (2022). Entitled "Factors affecting electric vehicle adoption intention. “This study evaluates the objective, perceived and future accessibility of public electric vehicle charging facilities, examining the influence and extent to which these new accessibility metrics affect individuals' intentions to adopt electric vehicles. Findings show that objective accessibility markedly and significantly influences people's intention to own an electric vehicle. Simultaneously, perceived and anticipated accessibility are critical to non-owners' intentions to use electric vehicles. We also note sizable effects on perceived and anticipated driving distance, environmental awareness, and prior experience with electric vehicles. This study offers a significant reference on the influence of public electric vehicle charger accessibility on electric vehicle adoption in densely populated Asian urban environments.

Meanwhile, research conducted by Qian, L., et al (2024). In their research entitled “Spatial cross-side network effect of charging stations on electric vehicle adoption “ Electric vehicle (EV) Charging infrastructure has a large impact on the adoption of Electric Vehicles (EV). Using quarterly panel data of charging availability for Tesla across states in the United States, we find that a 1% increase in charging availability at the state level and in input states has a positive correlation with increases in electric vehicle ownership by 5.75% and 1.09%, respectively

2.2.11.3. Socio-Economics Factor effect on Electric Vehicle Adoption

In the research of Bushnell, J. B., et al. (2022). Entitled. “Energy prices and electric vehicle adoption” This paper also explores that fuel price is more influential on the demand of EVs than cost of electricity in the State of California. Using a finely-grained panel dataset on monthly EV registrations in California, coupled with rich data on petrol and electricity prices, for the years 2014-2017, we provide an investigation of how energy prices impact demand for EVs. Two distinct empirical methodologies (panel fixed effects and utility boundary discontinuity) provide remarkably analogous outcomes: a specific alteration in petrol costs has around four to six times the influence on electric vehicle demand relative to an equivalent percentage variation in electricity prices. We examine the ramifications of optimal electric vehicle subsidies that capitalise on externality reduction advantages and rectify consumer optimisation errors arising from the underestimation of future electricity expenses.

Meanwhile, research conducted by Zhuge, C., et al . (2020). In their research entitled “ The potential influence of cost-related factors on the adoption of electric vehicle: An integrated micro-simulation approach “ This paper investigates the effects of first and operating marginal costs with two episodes devoted to the adoption of EV, including purchase subventions and fuel costs. Based on an integrated agent-based micro-simulation model, SelfSim-EV, the study explores the impact of PHEV subsidies, gasoline price and electricity price on Beijing EV market in 2016-2020 under different scenarios. Moreover, at such a detailed level, the model changes the urban field, electricity infrastructure, and EV-related facilities. The conclusions show that the impact of electricity and gasoline prices is negligible for EV adoption.

Regarding the environment awareness study conducted by Okada, T., Tamaki, T., & Managi, S. (2019). in a study entitled "Effect of environmental awareness on purchase intention and satisfaction pertaining to electric vehicles in Japan " This study addressed the intention of electric vehicle (EV) non-owners and their satisfaction after the purchase of an EV by using an online survey. Structural Equation Modeling (SEM) was employed to examine the relationships between these variables. The researchers also explored attitudes toward the environment. We compared the purchase intentions of non-EV owners with their expected satisfaction after owning an EV. The results suggested a clear discrepancy between the purchase intentions of non-EV owners and the satisfaction of EV owners. It demonstrated that environmental awareness has a direct effect on the purchase intention of non-EV owners and indirectly impacts the post-purchase satisfaction of EV owners.

Meanwhile, research conducted by Wang, Y., & Witlox, F. (2025). In their research entitled "Global trends in electric vehicle adoption and the impact of environmental awareness, user attributes, and barriers " The paper explores the spatiotemporal characteristics of several determinants of the adoption of different EV types. The present study uses meta-regression to aggregate 38 seminal and important investigations ranging from 1990 through 2023. More specifically, it investigates the key determinants of the adoption of Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs). The results suggest that numerous important variables have a significant influence on electric vehicle acceptance. Based on the meta-regression results, environmental sensitivity ($\beta = 0.23$), user attributes ($\beta = 0.17$), barriers ($\beta = -0.07$), and user knowledge ($\beta = 0.12$) are significantly important drivers of worldwide electric vehicle adoption behaviors. Interestingly, BEV adoption shows the strongest spatial influence in European countries ($\beta = 0.17$). Additionally, in the largest greenhouse gas-emitting nations, such as China and India, there is broad-based support for electric vehicles.

Regarding income per capita study conducted by Okada, T., Tamaki, T., & Managi, S. (2019).in a study entitled " Income, political affiliation, urbanism and geography in stated preferences for electric vehicles (EVs) and vehicle-to-grid

(V2G) technologies in Northern Europe” Applying bivariate statistical analysis and hierarchical regression to the data from more than 5,000 individuals sampled from Denmark, Finland, Iceland, Norway, and Sweden, this study examines the relationship between income, political ideology, and geography, on the one hand, and perceptions and attitudes to EVs and V2G on the other. Income is also a frequently identified factor for EV ownership and driving behaviors—people with higher incomes are more likely to own EVs and drive more—as well, though the things people find interesting about EVs are not similar. People with lower incomes usually have fewer cars—could a low-cost model be a good opportunity for them?

Meanwhile, research conducted by Xue, C., et al. (2021).. In their research entitled “Impact of incentive policies and other socio-economic factors on electric vehicle market share: A panel data analysis from the 20 countries” This paper analyses the worldwide diffusion of electric vehicles (EVs) through panel data and national/regional-based initiatives in addition to socio-economic factors. Results show that tax cuts, charging stations, and an increase in income level play positive roles in EVs' adoption. Therefore, the authorities are advised to continue the current tax rebate and to invest in the charging equipment. Furthermore, socio-economic factors such as the average household income are found to be the most influential on the EV adoption rate. Such insights can help policymakers and stakeholders further develop and rank the relevancy of measures to stimulate the uptake of EVs.

2.2.11.4. Theory DOI and TPB on Electric Vehicle Adoption

In the research of Moon, S. J. (2021). Intitled “ Integrating Diffusion of Innovations and Theory of Planned Behaviour to Predict Intention to Adopt Electric Vehicles” This research adopts the electric vehicle (EV) innovation and examines how consumers perceive this innovation to contribute to promoting EV prevalence. Thereafter, the paper proposes a multi-theoretical model combining the diffusion of innovations theory and the theory of planned behaviour to explore the influence of consumers' perceived innovation characteristics on the decision to adopt EVs. Findings show that consumers' perceptions of EV innovation characteristics have a positive impact on attitudes and intentions to use these sustainable motor vehicles. A number of salient features of the innovation have relevant practical implications for promoting the penetration of electric vehicles in the market.

Meanwhile, research conducted by Adam, B. M.,et al. (2024). Intitled“ Engaging Early Consumers: How BYD Leads EV Diffusion in Indonesia“ investigated the digital marketing strategies of two top-selling electric vehicle brands: BYD and Wuling, and examines their Instagram posts to examine how they target early adopters. By adopting 7 content categories from the Diffusion of Innovation Theory model, this study identifies 6 main categories of Instagram content and conducts a detailed analysis of one of the Product Information subcategories. The findings show that BYD focuses on technological innovation, future concept design, and convenient specifications, which meet the needs of early adopters. Meanwhile, Wuling also relies on driving comfort and interaction that will appeal to a wider range of consumers.

2.2.11.5. Theory Institutional on Electric Vehicle Adoption

In the research of Khatua, A., Kumar, et al (2023). Entitled” Institutional enablers of electric vehicle market: Evidence from 30 countries” This study examines how societal-driven legitimacy concerns are connected to electric vehicle (EV) markets in different countries. We speculate how the associations might be intertwined: different technological, business and cognitive pillars with EV sales. We test these hypotheses with secondary data from 30 countries, covering the years 2011 to 2020. The technique for analysis is multivariate regression with correction by panel standard errors to handle heteroskedasticity, inter-panel correlation, and auto regressivity. Empirical evidence suggests that institutional isomorphism resulting from public perception has a positive relationship with the EV market. The implications of this study offer guidance to policymakers in creating a sustainable EV ecosystem.

Meanwhile, research conducted by Lim, W. K., et al (2024) entitled "Electric Vehicle Choices in Malaysia: A Conceptual Model Investigating Switch Intention through a Push-Pull-Tow Model" (EVs) have experienced substantial growth and acceptance worldwide. However, data shows that the adoption rate of EVs in Malaysia is still quite low. Therefore, this study aims to investigate individuals' intention in switching from conventional to electric vehicles by applying the Push-Pull-Mooring (PPM) model that integrates institutional theory.

CHAPTER III
METHODOLOGY

3.1. Research Design

The study was conducted using a quantitative approach to examine the influence exerted by five policy variables, charging stations, environmental awareness, per capita income and fuel prices on the adoption of electric vehicles globally, EV sales volume being a proxy in this regard. The study covers a wide range of macroeconomic control variables to ensure the reliability and validity of the findings. A series of control variables were used in the study to further investigate the factors affecting the growth of electric vehicle sales. These variables include population and urbanization. The study looked at the influence of countries with the largest EV sales rates in the world and developing countries that adopt EVs, the number of countries used is 11 countries that represent the largest EV sales in the world and 6 countries that are developing countries. the country that has the largest EV sales. The country's ranking is based on references to the International Energy Agency (IEA), a body that measures the use of clean energy and technologies in the world. The study period in this study covers 6 years from 2018-2023.

3.1 Country Classification

Countries with the most electric vehicle adoption	Countries with Emerging Electric Vehicle Adoption
China	India
United State	Brazil
Germany	Thailand
France	Indonesia
United Kingdom	Mexico
Netherlands	Turkey
Norway	
Canada	
Japan	
South Korea	
Italy	

Author's Compilation

The country groupings in this study are based on the International Energy Agency (IEA). Various categories are used by the IEA for its member countries and global partners based on energy, policy, environment, level of development, and technology adoption, sometimes including the role of new and emerging clean developments such as electric vehicles. These groupings are used to encourage structured comparisons and contrasts of the electric vehicle adoption process across different country contexts, between high, medium and low adoption countries.

The International Energy Agency (IEA) is an intergovernmental organization created in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD). The IEA is an intergovernmental organization that acts as a policy advisor on energy issues, including energy security, economic development, environmental protection, and worldwide engagement. The IEA's mission is to ensure secure and reliable energy for its member countries and beyond, and to promote sustainable energy policies that support a strong and clean global energy system. The country categories used in this study are based on the divisions in the IEA's country classification reference, which allows for a more analytical approach to how policy, infrastructure and socio-economic development will affect the rise of electric vehicles in different types of countries.

3.2. Data and Collection Methods

This article is based on secondary data, which is defined as data collected by other people (authors) or institutions (organizations) for their own purposes. There are several strengths associated with using secondary data, which arise from careful data collection and validation efforts from various credible institutions with adequate infrastructure and resources. These sources may include government agencies, research groups, think tanks, scholarly journals, or reputable online databases. This study uses appropriate and reliable sources to collect comprehensive data, ensuring data accuracy, detail and reliability. Secondary data sources in this study include references cited in the literature review, academic articles, and official websites of major global institutions such as the World Bank and the International Energy Agency (IEA), investing, as well as intelligence on core minerals from the IEA and information on electric vehicle trends.

3.2. Data and Corresponding Sources

Variable	Definition	Measurement	Sources
Dependent Variable			
Electric Vehicle	Number of electric vehicles sold in one year. BEVS, HEVS, FCEVS, PHEVS (Cars, Van, Buses, Trucks)	Total Sales per year's (unit)	International Energy Agency (IEA)
Independent Variable			
Policy	Government support through incentive or regulatory policies for EV.	Index Score (0-1)	International Energy Agency (IEA)
Charging Station	Availability of charging station infrastructure for EV.	Number of charging stations per year's	International Energy Agency (IEA)
Environmental Awareness	Environmental Performance Index (EPI)	Score (0-100)	Environmental Performance Index (EPI) by Yale
Income per capita	GDP per capita	GDP per capita (current US$)	World Bank
Fuel Price	Price of fossil fuels per liter. Price of January every year's	US Dollar per liter	Investing.com
Control Variable			
Population	The number of inhabitants in a country or region.	Population in largest city	World Bank
Urbanization	Urbanization rate or the percentage of the population living in urban areas.	Percentage of urban population (%)	World Bank

Author's Compilation

In this study, the dependent variable is electric vehicle sales data, which covers all types of four-wheeled electric vehicles: passenger cars, vans, buses, and trucks. This data is taken from the official report of the International Energy Agency (IEA), with the unit of measurement being the total units sold per year. This approach aims to provide a comprehensive overview of electric vehicle adoption across various market segments. According to the International Energy Agency (2023). Light electric vehicles (such as two- and three-wheeled electric motorcycles) are not included in this study due to significant differences in market structure, consumer usage patterns, and limited harmonized data across countries for this type of vehicle. Several studies—focused on Southeast Asia and the two-wheeled motor vehicle market—indicate that E-2W and E-3W dominate urban mobility in developing markets, but have different adoption drivers compared to four-wheeled electric vehicles Kim et al, (2025). Cross-country surveys in Europe and Asia also reveal differences in user perceptions and policy environments for LEVs, making them less comparable in empirical panel data models, Mesimäki & Lehtonen, (2023).

3.3 Data Analysis

This paper uses panel data analysis, which is developed by combining time-series and cross-sectional data sets, from several observations of different units at different times. The dataset consists of data from seventeen countries, which are divided into two groups: eleven countries with the most electric vehicle adoption and six countries with emerging electric vehicle adoption. The study spans six years, 2018-2023.Gujarati (2004) defines panel data as data collected in repeated observations of individuals, firms, states, or countries over time. The advantage of panel data is the possibility to exploit cross-sectional and time-series information that may be less correlated, more informative, possibly more diverse, and more efficient by having more degrees of freedom. Such data are very useful in the identification and measurement of effects that would be missed if only cross-sectional or time-series data were used. Estimates are drawn from a balanced panel where each cross-sectional unit presents an identical number of time-series observations (Brooks, 2019).

3.3.1. Hypothesis variable

This variable hypothesis is a hypothesis that describes the initial hypothesis but the evidence of previous research, about whether the independent mining production, environmental performance (country level), , environmental performance (company level) has a relationship affecting the dependent variable Vehicle (EVs) Growth.

Before discussing the empirical findings, It is crucial to describe the hypotheses based on those presented in Chapter 2 before going over the empirical results. This section solely concentrates on the direct impact of each distinguishing variable in order to structure the conversation. Along with the empirical results, various interaction effect hypotheses will be covered in the following chapter.

3.3.1.1. Policy

The impact of Policy on Electric Vehicle Growth (EVs) has an impact on the adoption of EVs from the Government policy side. (*Hypothesis 1*). "The effect of policy incentives on electric vehicle adoption" The study was conducted by Langbroek, J. H., et al. (2016) , The purpose of this study is to investigate the impact of a range of policy incentives, in addition to socio-psychological factors, on electric vehicle (EV) adoption by employing Protection Motivation Theory (PMT) and the Trans-Theoretical Model of Change (TTM). This research also contends that political incentives, ex-option period, would increase the probability of adopting EVs since cost of using EV decreases. The return from such incentives is a cost-effective way to put in place costly subsidies, like free parking or use of bus lanes. Those who are inclined to be early in changing will be more likely to accept EVs, yet individuals who have already achieved a high state of change might act less sensitive to incentives. People are more likely to choose EVs when they see it as an effective solution to the downside externalities of their current transportation system, and when their traveling patterns are in line with this possibility.

3.3.1.2. Infrastructure

Similar to Policy charging station also has impacts the adoption of electric vehicles (EVs), (*Hypothesis 2*). According to Renaud-Blondeau, P., et al. (2023)., "Powering the transition: Public charging stations and electric vehicle adoption in Montreal," Knowing how public charging infrastructure is affecting the EV market is important for planners and politicians, and this is even more the case now that the EV market and EV charging become increasingly popular. This study investigates the influence of public charging infrastructure on electric vehicle (EV) adoption in urban contexts based on evidence provided by a survey conducted in Montreal, Canada, with over 642 respondents. The research evaluated objective (residences with access to charging stations), perceived (how people feel about the infrastructure concerning the existing public charging network), and prospective (opinions about how the public charging network will look in five years) accessibility metrics. Results show perceived and intended accessibility plays a greater role than objective measures, suggesting that potential users' perception shapes the development of the public charging infrastructure. Additionally, non-EV owners also commonly perceive a greater lack of availability of public chargers, suggesting a more serious gap in subjective evaluations. Based on these findings, programs targeting public awareness of the availability of charging stations could help stimulate greater adoption of electric vehicles in addition to any investment in public charging infrastructure. Significance: This work contributes to understanding how the integration of access-focused policies in electrification strategies can facilitate the adoption of EVs in urban contexts and highlight the importance of perceptions and expectations.

3.3.1.3. Environmental Awareness (EPI Score)

On the other hand, environmental awareness also has impacts of developing electric vehicles, especially in the side countries with a high EPI score (*Hypothesis 3*). According to the World Resources Institute(WRI) study, “These Countries Are Moving Fastest to Electric Vehicles,” the environmental performance of countries leading the shift is highlighted, as well as global EV adoption. Global Electric Vehicle Sales Growth: 10% of passenger cars sold worldwide will be electric by 2022, a tenfold increase from five years earlier. The report highlights that compared to cars with internal combustion engines, electric vehicles emit fewer greenhouse gases. The environmental benefits of electric vehicles are anticipated to grow as countries move toward a zero-carbon electricity grid, making EV adoption a critical part of reducing transportation- related emissions. The analysis shows how the environmental performance of countries with a high (EPI) and EV adoption rates correlate, highlighting the importance of supportive infrastructure and policies in accelerating the shift to electric transportation.

3.3.1.4. Income per Capita

From a socio-economic perspective, income per capita also has an impact on EV adoption according to; Chen, C. F., de Rubens, G. Z., Noel, L., Kester, J., & Sovacool, B. K. (2020). (*Hypothesis 4*). In their study titled "Assessing the Socio-Demographic, Technical, Economic and Behavioural Factors of Nordic Electric Vehicle Adoption and the Influence of Vehicle-to-Grid Preferences," the authors explore the interconnections among socio-demographic, economic, technical, and behavioural factors that shape preferences for vehicle-to-grid mobility solutions and intentions to adopt electric vehicles (EVs). Through a survey conducted with 4,885 participants across Denmark, Finland, Iceland, Norway, and Sweden, they applied hierarchical regression analysis to examine six dimensions related to these areas. The results indicate that younger men with higher incomes tend to have more children and prior experience with EVs, as well as favorable sustainability ratings when considering the adoption of electric vehicles. The analysis reveals that among all factors—including fuel savings, financial benefits, and environmental considerations—the network's capacity to enhance income plays a significant role in driving EV adoption.

3.3.1.5. Fuel Price

Socio-economic also Fuel prices found to have positive impact on EV adoption, Zhao, X., Li, X., Wang, A., & Fang, J. (2025). (*Hypothesis 5*). In their research; The impact of energy prices on electric vehicle adoption: From a perspective of consumer expectations. In the interest of contributing to a better understanding of the relation between energy prices and the adoption of electric vehicles (EV), which is a key factor in the foment of sustainable transportation, this paper offers a methodological and an empirical dimension. It examines the heterogeneous effects of fuel and electricity price changes on EV adoption in 50 cities of China over the period 2010-2020 by employing a discrete choice model combined with a regression discontinuity design. This approach allows for properly estimating the causal effect of energy prices while accounting for putative confounders. It uses empirical data to estimate the relative strength of the gasoline price effect in comparison to electricity prices on consumer adoption, which is 3.5 to 6 times more for most of the investigated vehicles. Further, the analysis uses a novel framework to account for consumer misperceptions about future electricity expenses, finding that between 0% and 37% of the optimal subsidy for an electric vehicle (40% in per vehicle terms) can be attributed to these misconceptions.

3.3.2. Panel Data Regression

This study relies on the panel data regression method to handle data and conduct research. Panel data regression is a statistical method that uses statistical operations on cross-sectional data, which are measurements of one or more variables collected at a single point in time for some or all entities. This aggregation increases the number of observations and thus tends to be more robust (Gujarati, 2004). The general form of the model equation for panel data regression is described by the equation given by Baltagi (2005).

$$Y_{it} = \beta 0+\beta 1X1_{it}+ \beta 2X2_{it}+\dots \dots+ \beta nXn_{it}+\epsilon_{it} \quad (3.1)$$

Yit = Dependent variable

β0 = Intercept coefficient

β1, β2, βn = Coefficients assigned to each independent variable.

ε_{it} = error term in prediction.

$$EV\_Sales_{it}=\beta_0+\beta_1 Policy_{it}+\beta_2 Income_{it}+\beta_3 Infra_{it}+\beta_4 Fuel\_Prices_{it}+EPI_{it}+\beta_6 Population_{it}+\beta_7 Urbanization_{it} +\varepsilon_{it} \quad (3.2)$$

In this panel data model, EV_Sales_{it} is the dependent variable that records the sales of electric vehicles (EVs) in country (i) in year (t). This variable is the most important outcome that needs to be analysed here as an indicator of the acceptance of electric vehicles in a country at a particular point in time. The first independent variable is Policy_{it}, which represents the government policy in country (i) in year (t). The measure can be incentives, for example, subsidies for the purchase of electric vehicles, tax exemptions, and/or regulations that encourage the use of environmentally friendly vehicles in the form of dummies. Meanwhile, Income_{it} is the per capita income in country (i) and year (t). A higher income level implies a higher economic capacity of the consumer population, which enables the purchase of electric vehicles, which are generally more expensive than conventional vehicles. Infra {it} is a proxy for the presence of charging stations in country (i) in year (t). The presence of charging facilities is an upstream component in mitigating range anxiety or consumer uncertainty about the range of electric vehicles, and therefore adoption prospects.

Fuel Price reflects the estimated price of fossil fuels in country (i) in year (t). More expensive conventional vehicles create more demand for electric vehicles as a more cost-effective alternative to cover high fuel costs. EPI_{it} reflects the level of environmental awareness in country (i) in year (t). Increased attention to environmental issues (e.g., climate change, air pollution) may affect consumer preferences regarding the use of EVs measured in the EPI index. Population_{it} is the population of country (i) in year (t). Population alarms highlight the potential of broadband markets to stimulate EV sales. Urbanization_{it} is the urbanization rate in country (i) in year (t). Large urbanization (high urbanization) is a category characterized by high population density in urban zones, where electric vehicle infrastructure is more advanced, and awareness of environmental issues is relatively higher, which stimulates electric vehicle adoption. Finally, epsilon_{it} is an error term that indicates fluctuations in electric vehicle sales that are not accounted for by the determinants included in the model. The expression further includes what is not part of the analysis that affects electric vehicle sales.

Panel data regression models can be estimated through a number of panel data analysis methods, namely common effects, fixed effects, and random effects. The fixed effects (FE) model assumes that there are no cross-section unit-specific effects. Meanwhile, the FE model adjusts for individual fixed differences between units, and the RE model treats these as random differences and uncorrelated with the regressors.

3.3.2.1. Fixed Effect Model

According to Winarno (2015), the fixed effects approach is characterized by an object maintaining a consistent value across different time periods. In this context, the regression coefficient may also be stable over time (time invariant). The fixed effects model posits that while each subject's slope remains unchanged throughout the observation period, their intercepts differ from one another (Gujarati, 2004). This means that every subject has a distinct intercept, but shares a uniform slope. To differentiate between subjects, dummy variables are employed (Kuncoro, 2012). The technique involving dummy variables is utilized to estimate the Fixed Effects Model with varying intercepts among individuals. This estimation method is often referred to as the Least Squares Dummy Variable technique, or LSDV for short.

$$EV\_Sales_{it}=\beta_0+\beta_1 Policy_{it}+\beta_2 Income_{it}+\beta_3 Infra_{it}+\beta_4 Fuel\_Prices_{it}+\beta_5 Environmental\_Awareness_{it}+\beta_6 Population_{it}+\beta_7 Urbanization_{it}+\varepsilon_{it} \quad (3.3)$$

EV_Sales_{it}	= Electric Vehicle Sales per year (unit)
β_1- β_5	= Regression Independent Variable
$Policy_{it}$	= Policy (Index Score (0-1)
$Income_{it}$	= GDP per Capita ($ per year)
$Charging\_Stations_{it}$	= Charging Stations (Number of charging stations)
$Fuel\_Prices_{it}$	= Fuel Price ($ per liter, Average price)
Environmental_Awareness	= Environmental Performance (EPI Index)
$Population_{it}$	= Population (Growth per year (%)
$Urbanization_{it}$	= Urbanization (Urbanization Population (%)
i	= The individual i-th,
t	= The time t-th.
ϵ_{it}	= The error term

3.3.2.2. Random Effect Model

A panel data fitting method that allows for (and estimates) residual correlation over time and between individuals is the random effects model. This model can also be called an error component model, because it allows for variation that occurs at the individual level as well as across different time periods in the error term. This is distinctly different from a fixed effects model, where optimization is more concerned with the number of entities than with degrees of freedom. When selecting a regression model, the first step is to use the Chow test, which distinguishes between common effects and fixed effects methods. Using a least squares dummy variable (LSDV) Fixed Effects approach can provide an indication of model uncertainty.

$EV\_Sales_{it}=\beta_0+\beta_1 Policy_{it}+\beta_2 Income_{it}+\beta_3 Infra_{it}+\beta_4 Fuel\_Prices_{it}+\beta_5 Environmental\_Awareness_{it}+\beta_6 Population_{it}+\beta_7 Urbanization_{it} +\varepsilon_{it}$ (3.4)

EV_Sales_{it}	= Electric Vehicle Sales per year (unit)
β_1- β_5	= Regression Independent Variable
$Policy_{it}$	= Policy (Index Score (0-1)
$Income_{it}$	= GDP per Capita ($ per year)
$Charging\_Stations_{it}$	= Charging Stations (Number of charging stations)
$Fuel\_Prices_{it}$	= Fuel Price ($ per liter, Average price)
Environmental_Awareness	= Environmental Performance (EPI Index)
$Population_{it}$	= Population (Growth per year (%)
$Urbanization_{it}$	= Urbanization (Urbanization Population (%)
i	= The individual i-th,
t	= The time t-th.
ϵ_{it}	= The error term

3.3.2.3. Common Effect Model

The simplest fundamental model or estimation technique in panel data regression that nevertheless applies the ordinary least squares approach is the common effect model. As a result, another name for this technique is pooled least squares. It can be assumed that individual behaviour does not change over time because this common effect model ignores both the individual and cross-sectional dimensions as well as the time dimension. When estimating regression models with panel data, a number of techniques are frequently employed, including the fixed effect approach, the random effect approach, and pooling least squares (common effect). Cross-sectional and time-series data are combined to create panel data. Kuncoro, Mudrajat. (2003).

$EV\_Sales_{it}=\beta_0+\beta_1 Policy_{it}+\beta_2 Income_{it}+\beta_3 Infra_{it}+\beta_4 Fuel\_Prices_{it}+\beta_5 Environmental\_Awareness_{it}+\beta_6 Population_{it}+\beta_7 Urbanization_{it} +\varepsilon_{it}$ (3.5)

EV_Sales_{it}	= Electric Vehicle Sales per year (unit)
β_1- β_5	= Regression Independent Variable
$Policy_{it}$	= Policy (Index Score (0-1)
$Income_{it}$	= GDP per Capita ($ per year)
$Charging\_Stations_{it}$	= Charging Stations (Number of charging stations)
$Fuel\_Prices_{it}$	= Fuel Price ($ per liter, Average price)
Environmental_Awareness	= Environmental Performance (EPI Index)
$Population_{it}$	= Population (Growth per year (%)
$Urbanization_{it}$	= Urbanization (Urbanization Population (%)
i	= The individual i-th,
t	= The time t-th.
ϵ_{it}	= The error term

3.3.3. Selecting the appropriate method

The process of selecting the right model for panel data regression is highly dependent on accurate and responsible statistical data processing. This panel data is specifically formed in this study by selecting the most appropriate model from three types. According to Widarjono (2009) in his research related to panel data analysis, there are three methods of estimating panel data regression models, namely: Fixed Effect Model (FEM), Random Effect Model (REM), Common Effect Model (CEM).

3.3.3.1. Chow Test

The Chow test aims to investigate which model—whether the Fixed Effect Model (FEM) or the Common Effect Model (CEM)—is appropriate for examining panel data. It tests these two models using the EViews program for implementation in this study. The Chow test is used to decide on the best model for the panel data providentially for both fixed and common effect models. The Chow test takes the cross-section F-value as the decision-making criterion. An overall $P < 0.05$ would indicate preference for the common effect model. On the other hand, when the P F-value is less than 0.05, the FE model is considered to be more appropriate. (Widarjono, Agus. 2009).

3.3.3.2. Lagrange Multiplier Test

In panel data modelling, the Lagrange Multiplier test is used to choose the best model between common effect and random effect models. The names, "Lagrangian Multiplier Test" and "Lagrange Multiplier Test" are pointing out to the same analysis method to test, for the optimal estimation method whether or not the random effects are present. This test is useful to determine whether a fixed effect or a random effect is more important.

The test of the Lagrange Multiplier (LM) only judges the appropriateness of the Random Effect method. It can discriminate Random Effect from OLS (Common Effect that does not have dummy variables) by LM test through this LM test. Bruesch-Pagan introduced this significance test for the Random Effect model. Finally, the purpose of the LM test is to compare and measure the benefit of the

Random Effect approach compared to OLS (common Effect) at large. (Widarjono, Agus. 2009).

3.3.3.3. Hausman Test

Hausman test is a method to decide during analysis if the fixed effect model or random effect model should be used. The Hausman Test, which is simply a comparison of the two, drives the difference between these two models. In this tutorial, we'll discuss how to run the Hausman Test in Stata for a Panel Regression model. In panel data analysis, the Hausman test is used to determine the most appropriate model based on which method, fixed or random, is the best. The decision of the Hausman test is based on the probability value of the random cross-section. If this p-value is <0.05, the fixed effects model is appropriate. If this value is less than 0.05, we conclude that the suitable model is the fixed effect model, whereas if the p-value is greater than 0.05, the random effect model is considered as suitable.(Widarjono, Agus. 2009).

CHAPTER IV

RESULT AND DISCUSSION

4.1. The Current condition of Electric Vehicle Adoption

Electric vehicles are an invention that can reduce greenhouse gas emissions and mitigate factors contributing to climate change. However, externalities such as knowledge application and pollution mitigation generate social and economic benefits that are not reflected in the price of electric vehicles. The government has enacted various policy programs to correct the market failure. Socio-economic considerations, charging infrastructure, and the presence of local production facilities are important elements that are positively associated with a country's electric car market share. Sierzchula, W., et al. (2014).

The global automotive sector is undergoing a significant transition, with electric vehicles (EVs) leading this revolution. By 2023, the electric vehicle market is expanding rapidly, as more automakers pledge to electrify and governments around the world set aggressive goals to reduce carbon emissions. The advantages of electric vehicles are undeniable: reduced greenhouse gas emissions, reduced operating costs, and a cleaner, more sustainable transportation future. However, despite the clear benefits, there are still major barriers that hinder the widespread use of electric vehicles. Exro Technologies. (2023). By 2023, approximately 14 million new electric vehicles will be registered worldwide, resulting in a total of 40 million electric vehicles on the road, according to sales projections from the Global EV Outlook 2023 (GEVO-2023). Electric vehicle sales in 2023 are projected to exceed 3.5 million compared to 2022, which represents a 35% year-on-year increase. International Energy Agency. (2024).

After a decline in electric vehicle sales in 2022, Europe represented 25% of worldwide electric vehicle sales in 2023 and is anticipated to maintain growth in 2024, remaining the second largest electric vehicle market after China. Electric vehicle sales are projected to exceed 20% in 2023 compared to 2022, approaching 3.2 million units. In the European Union, the number is around 2.4 million units. Electric vehicle sales in Europe have consistently increased in most countries, with the exception of Germany, where the share of sales decreased from 30% to 25%, mainly due to the reduction of certain purchase subsidies. Virta Global. (2024).

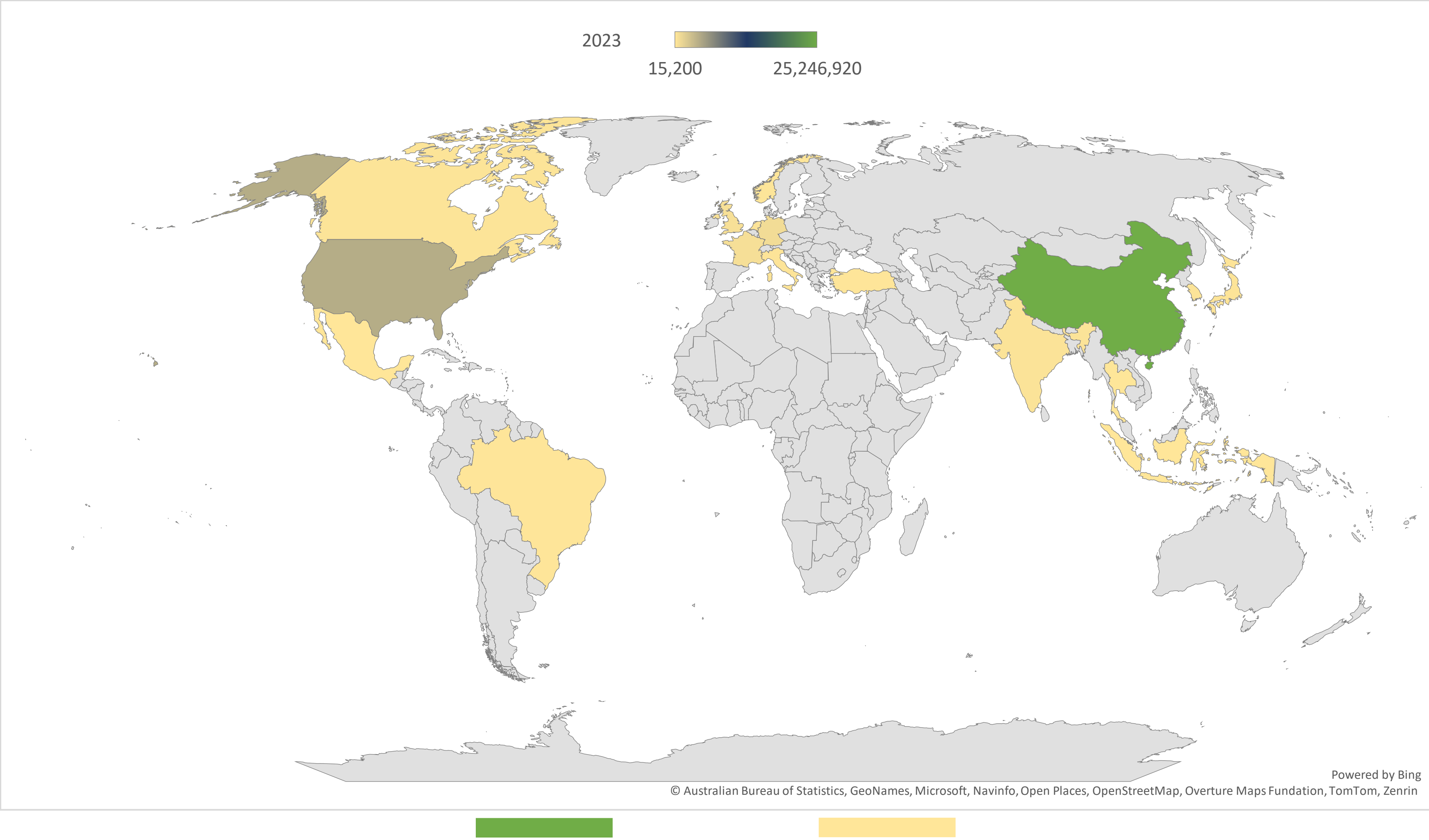


Figure 4.1. Trends in electric vehicle adoption, proxied by EV sales in 17 countries (2018–2023) in thousand million.
Sources : Source: IEA, (2023b)

Sales were largely driven by China, which recorded 11 million electric vehicles and plug-in hybrids, reflecting a 40% increase from the previous year, and accounting for about two-thirds of global sales. Europe ranked second with 3 million, which accounted for 18% of new electric car sales; however, sales decreased 3% compared to the previous year due to the expiration of some government subsidies. North America represented 1.8 million, exceeding 10% of worldwide electric car sales, although it is projected to experience only 9% growth by 2024. Global electric car sales are projected to increase significantly to 1.3 million, representing a 27% increase from 2023. Nuccitelli, D. (2025).

4.2. Current State of countries with the high electric vehicle adoption

The rapid expansion of EVs illustrates the global automotive market's rapid transition towards electric mobility, driven by falling battery costs, improved infrastructure, and strong legislative support in significant markets. Countries such as China, the United States, and several regions in Europe are at the forefront of this transition, facilitating emissions reductions, reducing oil consumption, and promoting innovative technologies. Saptakee, S. (2025).While electric vehicle sales are growing worldwide, they are still highly concentrated in a number of key markets. By 2023, less than 60% of new electric vehicle registrations will be in the People's Republic of China (hereafter ‘China’), less than 25% in Europe,2 and 10% in the United States - which equates to almost 95% of global electric vehicle sales. International Energy Agency. (2024).

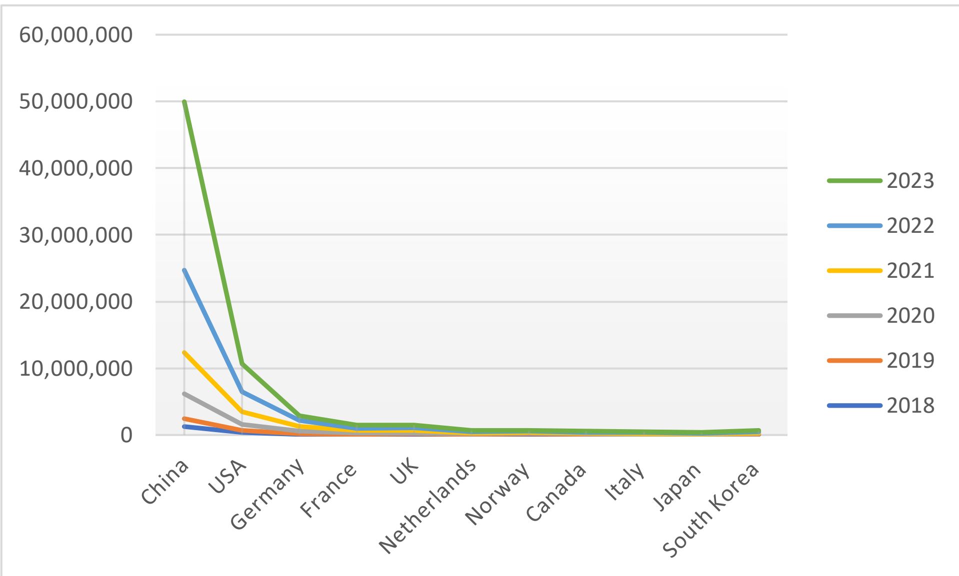


Figure 4.2. Evolution of EVs adoption in countries with the Highest EV Adoption, based on 2018–2023 EV sales data. in thousands of millions. in thousand million
Source: IEA, (2023b)

China is a major force in the electric vehicle market. By 2022, 22% of passenger vehicles sold in China will be fully electric, totalling 4.4 million units sold. This exceeds the total of 3 million electric vehicles sold globally. China's support for electric vehicles has contributed to reducing battery costs and facilitating global acceptance of electric vehicles. World Resources Institute. 2023 Counterpoint Research shows that the United States ranked second, ahead of Germany, in sales during the first quarter of 2023. China continues to be the world leader, with a 29% year-on-year increase in Q1 2023, despite a 12% decline in overall passenger vehicle sales during the same period. Although the US ranks second in EV sales, it significantly lags behind other countries in terms of the proportion of EVs sold in each country. According to a July 2023 USA Today article, which used statistics from Cox Automotive, “The U.S. electric car market share increased from 5.7% to 7.2% from April to June.” Maxwell, J. P. (2023).

The number of electric vehicles (EVs) in Germany continues to rise through 2023. More than 500,000 new battery electric cars (BEVs) have been registered. As a result, the German vehicle fleet currently consists of more than 1.4 million battery electric vehicles. By 2023, battery electric vehicles (BEVs), together with plug-in hybrids (PHEVs), account for around one third of newly registered electric cars. The relatively small increase in new electric car registrations compared to the previous year can be attributed to the decrease in electric car subsidies. In 2023, incentives for PHEV purchases will be discontinued, and subsidies for BEVs priced below EUR 40,000 will be reduced. Certification Panel. (2023)

In 2023, there will be 1,594,841 electric vehicles and plug-in hybrid vehicles on French roads, with 468,219 vehicles registered in that year. The market share of fully electric cars is close to 20%. According to the French European Electric Mobility Association (AVERE), the evolutionary implications of the ecological bonus from 2024 are worth considering. This temporary surge will further affect registrations at the beginning of the year. Nonetheless, this will not hinder the continuous increase recorded during 2020, where the total number of electric vehicles registered in France surpasses one million by December 2023. EVTCP. (2023).

Unexpectedly, the proportion of electric vehicle sales in the UK stagnates for the first time by 2023, raising concerns about manufacturers' ability to meet new environmental goals and fuelling demands for tax reductions in the sector. Electric vehicles accounted for 16.5% of new car sales in the UK last year, down slightly from 16.6% the year before. This indicates that one in eleven consumers are opting for electric vehicles, so Mike Hawes, director of the SMMT, emphasized the need for incentives for consumers in general. Garratt, E. (2025). It was even a more significant month for the electric vehicle sector in the Netherlands. José Pontes, EV-volumes.com data director, loftily reviewed the prime brands and models. A total of 13,795 electric vehicles was recorded in December 2023, comprising battery electric vehicles and plug-in hybrids. This proportion propelled the market share of plug-in technology to 52%, making it the most significant powertrain in the country. On their part, BEVs registered 42%. For the entire year, the electric car market share surged to 44%, up from 35% in 2022. Additionally, the 31% figure for BEVs accounted for the total annual registrations, increasing by eight percentage points compared to the previous year. Electric models, for their part, had a 71% proportion in the overall EV market, just above the 68% recorded in 2022 and below the 82% peak noted in 2020. Autovista Group, 2024.

In Norway, electric vehicles account for 88.9% of new car sales, up from 82% in 2023, as reported by the Norwegian Road Federation. During certain months of the year, registrations for new vehicles reach 98%, resulting in a decline in sales of fossil fuel cars. This puts Norway within reach of its 2025 goal (set in 2017) of achieving 100% electric new vehicles, making it the first country in the world to reach this milestone. Electric vehicles have surpassed gasoline vehicles in terms of their proportion in the road fleet. More than a quarter (28.9%) of all vehicles on Norwegian roads today are electric vehicles, compared to 23% gasoline, 36% diesel, and 12% hybrids. Electric vehicle sales are projected to surpass diesel sales by 2032, taking the entire market share. Power grid. (2025). In 2023, electric car sales in Canada reached 324,433 units, reflecting a 35% increase from the previous year. Electric vehicle sales in Canada have seen a consistent increase, rising from 10,624 units in 2011 to 324,433 units in 2023. The increase in the number of electric vehicles (EVs) in 2023 from 204,659 in 2022 by 35% (registered EVs is 324,433 in 2023) shows rapid progress and indicates conducive policies for the development of the market for EVs (Road Genius, 2024).After stagnating in 2022, the Italian plug-in vehicle market showed growth early in 2023. Still, the growth was slight, as sales fell to 2021 levels. The good news also hints at a troubling trend: Italy remains a laggard compared to other important European markets as far as the transition towards electric mobility is concerned. Sales of BEVs surged to 46,642 registered, reaching 4.2% of the total automotive market. Plug-in hybrid electric vehicles (PHEVs) had meanwhile recorded an equivalent market share of 4.4%, with 32,828 units sold in total (2024).

Annual electric vehicle sales in Japan would be at 11.9 million by the end of 2023, according to the firm's forecast. The electric vehicle market in Japan has been growing since 2011 and has experienced growth of up to 600%. That jump from 2022's 11.02 million units to the projected total of 11.92 million in 2023, an 8% gain, is a testament to the rapid growth and positive long-term electric vehicle penetration. Road Genius (2024).New electric vehicles bought in South Korea will comprise about 9 percent of new vehicle purchases by 2023, according to the Ministry of Land, Infrastructure and Transport. Electric vehicle chargers in the country now number over 200,000, the equivalent of two electric vehicles for each charger. According to the sales projection released by the Ministry of Land, Infrastructure and Transport on February 13, the combined car sales for 2023 are expected to be 1,749,729 cars, while 162,507 cars or 9.3 percent of all the sales will be electric cars. The percentage of electric vehicle new car purchases made by consumers has been increasing since 2019 when only 1.9 percent were electric, reaching a strong 98.7 percent in 2022.Park, S.-j. (2024).

4.3. Current state of the emerging Electric Vehicle Adoption Countries

In emerging countries outside China, cheaper electric vehicle alternatives are emerging, and the future for electric two-and-three-wheelers looks is expected that by 2023, between 55% and 95% of electric vehicle sales in emerging markets and large developing countries will be larger models that are typically too expensive for average consumers. In India and Southeast Asia alone, some 1.3 million electric two-wheelers are projected to be sold in 2023, representing 5% and 3% of the two-wheel market, respectively, as per addition, it is estimated that one in five of the worldwide three-wheeler sales will be an electric one, and 60% of it will be in India. This growth is mainly driven by incentives under the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) subsidy programme. International Energy Agency (2024).

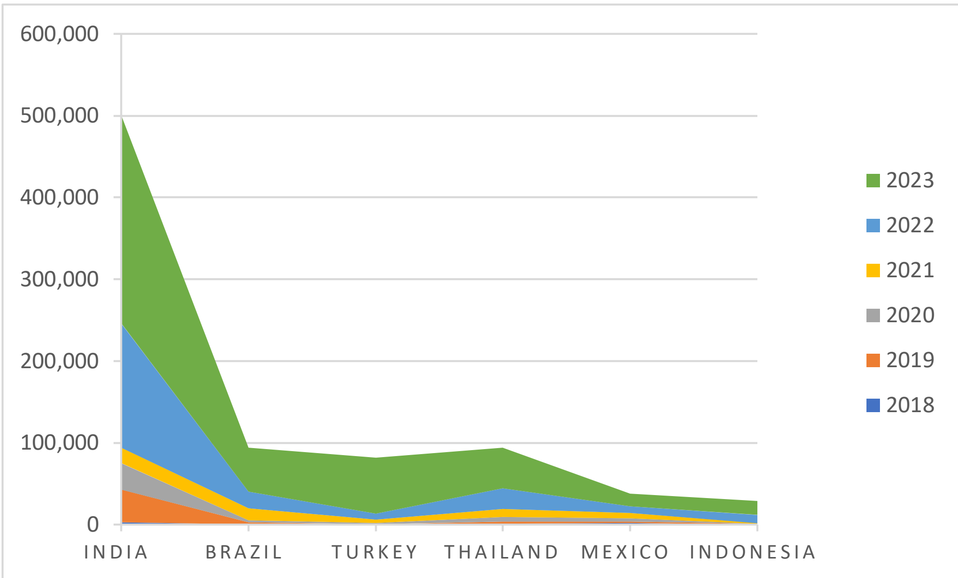


Figure 4.3. The evolution of electric vehicle adoption in countries with emerging EV markets, based on 2018–2023 EVs sales data. in thousand million
Source: IEA, (2023b)

Electric vehicle adoption in India jumped from 0.7% of total motor vehicle sales in 2020 to 6.3% in 2023. The country currently has around 5 million registered electric vehicles, preventing around 10 million tons of carbon emissions from 2020 to 2023, while reducing air pollution and creating employment opportunities. Investment in electric vehicles has increased significantly, totalling $15.13 billion from national and state governments and $6.4 billion from private financing. Regions such as Delhi and Chandigarh are at the forefront of electric vehicle adoption, while Tamil Nadu, which hosts significant automotive manufacturers, leads in electric vehicle production. World Resources Institute. (2025). Electric vehicle adoption in Brazil is still limited, but increasing: in 2023, battery-powered light vehicles represent 0.9% of total sales, rising to 2.6% if plug-in hybrid vehicles are included. In the first half of 2023, 3,778 battery electric vehicles were sold, but from July to December of the same year, sales jumped to 53,700 units, representing 1.25% of light vehicle sales during the period (ABVE, 2024). In 2023, the Brazilian market presented 101 electric vehicles, which is 9% of all accessible models in the country - a 600% increase from the 14 models offered in 2020. International Council on Clean Transportation. (2025).

In 2023, TOGG (Türkiye's Automobile Joint Venture Group) emerged as the leading electric vehicle manufacturer in Turkey with sales of 19,583 units increasing to 30,093 units in 2024, reflecting the significant progress of the first domestically produced electric vehicle brand, with an annual production capacity of 175,000 units and high growth potential. However, a survey conducted by Sarjagel.com shows that Turkish consumers' preferences still lean towards European electric vehicles (45.1%), followed by local (26.1%) and Chinese (14.8%) products. (2025,) In Southeast Asia, the dominance of Chinese electric vehicle manufacturers is evident, with three out of four electric vehicles sold in the first quarter of 2023 coming from China; Thailand leads the region by accounting for nearly 79% of total regional sales, driven by government incentives and a rapidly developing charging infrastructure. Kadence. (2024) Meanwhile, Mexico is also making great strides in the electric vehicle sector in the same year, recording projected sales of 15,200 units and attracting major investments from Tesla of $5 billion to build an electric vehicle production centre in Monterrey, as well as from Jet our of $3 billion in Bajo, making the country a major player in the global electric vehicle supply chain. On the other hand, Indonesia is beginning to show strategic potential as an EV market and development hub, recording sales of 7,105 units by 2023; although it still faces challenges, the long-term growth opportunities are enormous with the support of research, technology development, and utilization of local resources, especially in the context of energy transition and national industrial innovation.AC Ventures & Indonesian Electric Mobility Ecosystem Association. (2023).

4.4. Country classification and Regression Model Framework

This study examines 17 countries from different global regions. The country breakdown is based on the International Energy Agency (IEA) 2024 annual report which categorizes countries into two groups: countries with the highest electric car sales and countries with growing electric car sales. We use three different regression models to provide a more comprehensive analysis. Model 1 includes all 17 countries to provide regression results and provide an overview. Model 2 depicts the regression results for the 11 that show the largest electric car sales. Finally, Model 3 focuses on 6 countries that show growth in electric car sales.

4.5. Descriptive statistic

4.5.1. Descriptive Statistics of Model 1

Table. 4.1. Descriptive statistic of Model 1

Variable	Obs	Mean	Std. Dev.	Min	Max
ID	102	9	4.923172	1	17
YEARS	102	2020.5	1.716259	2018	2023
EVS	102	694215.1	2867418	0	25200000
POLICY	102	0.9901961	0.0990148	0	1
INFRA	102	102311.3	343746.4	0	2700000
EPI	102	60.51324	16.6484	18.9	83.95
FUEL	102	45538.32	19550.76	1918	61713
INCOME	102	33048.06	24957.32	1907.043	108798.5
URBANZ	102	13133.31	28596.78	34.031	83298
POPUL	102	18.44581	1.351761	15.48546	21.08657

The detailed statistics table shows for model 1covers all observations from various countries. Electric vehicle sales, which is the dependent variable EVS, has a mean of 694,215 units and a high standard deviation of 2,867,418, indicating that there are many differences between countries. There is a mean of 0.99 for the dummy variable POLICY, which means that almost all observations are in a policy regime that favours electric cars. The INFRA variable has an average of 102.311 but the range is very wide, indicating a lack of infrastructure. The mean value of the environmental measure EPI is 60.5, while the mean value of FUEL prices is 45,538. The average income (INCOME) per person is 33,048 USD. The average for URBANZ (urbanization rate) is 13,133 and the average for POPULAR is 18.45 million.

4.5.2. Descriptive Statistics of Model 2

Table. 4.2. Descriptive statistic of Model 2

Variable	Obs	Mean	Std. Dev.	Min	Max
ID	66	6	3.18651	1	11
YEARS	66	2020.5	1.720912	2018	2023
EVS	66	1060198	3519833	10401	25200000
POLICY	66	1	0	1	1
INFRA	66	157119.2	418281.1	3470	2700000
EPI	66	69.53348	11.74698	28.4	83.95
FUEL	66	45822.23	19440.64	1918	61713
INCOME	66	47131.41	19781.97	9905.406	108798.5
URBANZ	66	20261.63	33533.75	70.438	83298
POPUL	66	18.08475	1.384438	15.48546	21.06853

The detailed statistics table shows for model 2,11 countries 11 countries with the highest vehicle adoption from 2018 to 2023 show that the average electric vehicle (EV) sales amount to 1,060,198 units, accompanied by substantial variation (standard deviation of 3,519,833), highlighting disparities within countries. The POLICY variable is consistently equal to 1 across all observations, indicating that every country in the sample enacted a policy in favour of electric vehicles during the specified period. The average INFRA score of 157,119 indicates the varied availability of EV infrastructure, with the maximum value reaching 2.7 million units. The Environmental Performance Index (EPI) is 69.53, while the average fuel price (FUEL) is 45,822. The INCOME variable averages 47,131 USD, the average urbanization rate (URBANZ) is 20,261, and the population (POPUL) is 18.08 million.

4.5.2. Descriptive Statistics of Model 3

Table. 4.3. Descriptive statistic of Model 3

Variable	Obs	Mean	Std. dev.	Min	Max
ID	36	3.5	1.732051	1	6
YEARS	36	2020.5	1.732051	2018	2023
EVS	36	23247.25	48944.61	0	254766
POLICY	36	0.9722222	0.1666667	0	1
INFRA	36	1830.139	2669.998	0	10900
EPI	36	43.97611	10.43264	18.9	60.7
FUEL	36	45017.83	20017.42	4918	61713
INCOME	36	7228.585	3311.161	1907.043	13790.02
URBANZ	36	64.72508	18.54685	34.031	87.788
POPUL	36	19.10775	1.008417	18.08347	21.08657

This descriptive statistics are based on observations from 6 countries with adoption of developing electric vehicles, during the 2018-2023 period. The average sales of electric vehicles (EV) are 23,247 units, with high standard deviations (48,944), showing inequality between countries. The policy variable has an average of 0.97, shows that almost all countries in the sample have policies that support EV. The average infrared value is 1,830, showing the infrastructure for filling EV is limited in most countries. The Environmental Performance Index (EPI) has an average of 43.97, while the average fuel price (fuel) is 45,017. Average per capita income (income) 7,228 USD shows that most of the middle-income countries. Urbanization (Urbanz) and Population (Popul) have an average value of 64.72 and 19.1 million, respectively.

4.6. Classical Assumption Test

The classical assumption test in the regression model is used to assess the efficacy of the linear regression model and ensure the dependability of the results. The classical assumption test of this study includes assessments for multicollinearity, heteroscedasticity, and autocorrelation.

1. Multicollinearity Test

   The multicollinearity test is to find a strong relationship between two or more independent factors in a model. A number called the Variance Inflation Factor

(VIF) is often used to find multicollinearity. If the VIF number is higher than 10, this means that there is multicollinearity. Gujarati, D. N., & Porter, D. C. (2009).

For the results of models 1,2 & 3, there is a linear relationship between the independent variables, which is indicated by variables that have VIF values above the general standard (>10). For Model 1, the average value is 180.35. For example, the variables ln_INCOME and ln_POPUL are interrelated. This may be because population and economic activity in a region are closely linked. In addition, ln_FUEL is related to ln_INFRA and ln_URBANZ because people tend to use more energy when infrastructure grows and cities develop. This suggests that environmental policy and environmental performance are interrelated because the POLICY and EPI factors also have high VIF values.

In Multicollinearity Model 2, the variables URBANZ, INCOME, EPI, POPUL and POLICY experience multicollinearity because, conceptually, these five variables are interrelated in terms of development and policy. Urbanization (URBANZ) often grows along with income (INCOME) and population (POPUL). Conversely, increases in EPI and policy (POLICY) levels are generally higher for countries with high urbanization and income. This dependency causes correlation between factors, resulting in multicollinearity, while the INFRA and FUEL variables are free of multicollinearity.

In Model 3, the variables POPUL, INCOME, EPI, and POLICY are susceptible to multicollinearity, as they are all potentially empirically correlated with each other. Countries with high populations (POPUL) tend to have per capita income (INCOME) and environmental awareness (EPI) that grow over time. In addition, more economically developed countries are also more involved in environmental and electric vehicle policies (POLICY). These causal relationships lead to correlations among the variables, which gives rise to multicollinearity, while the INFRA, FUEL and URBANZ are free of multicollinearity.

According to Sholihin, M., & Anggraini, P. G. (2021). In overcoming variables affected by multicollinearity, the *centering* method is used, namely by creating a new variable from the results of subtracting the old variable from the average of the old variable. The results of passing multicollinearity are shown in appendices.

Alnins (2022) asserts that multicollinearity in the model does not distort the calculated coefficients. However, it does lead to an increase in the variance of the estimates, which results in higher standard errors and therefore reduces the statistical significance (p-value) of the model. The literature suggests that if the collinear variable is a control variable and not collinear with the main variable, then this is not a problem Allison,P.(2012).

2. Autocorrelation Test

   A regression model is considered effective if there is no autocorrelation. Autocorrelation tests arise from sequential observations over time that are related. Ajija, S.et al. (2011).

   This study uses the Wooldridge test, which is explained by Hoechle, D. (2006). To test for Autocorrelation. The Wooldridge test results for model 1, Prob > F (0.0001) and model 3 Prob > F (0.0001), are much smaller than the general significance level (0.05), then: H0 is rejected, there is autocorrelation, please see the appendix for more info. Therefore, according to Hoechle, D. (2006). when autocorrelation occurs, the way to overcome it is by using (ro) robustness. For model 2 results pass the autocorrelation test test because the selected model is the Random effect model, according Gujarati, Damodar N, Dawn C. Porter. (2010). The Random Effect Model (REM) considers the disturbance or error term as a stochastic element and incorporates the Generalised Least Squares (GLS) approach. REM effectively addresses heteroscedasticity and diminishes correlation with time in the dataset.

3. Heteroscedasity Test

   This study uses the Modified Wald Test & Breusch-Pagan/Cook-Weisberg, which is described by Hoechle, D. (2006). For model 1, the value of Prob> chi^2 = 0.0000 <0.05, then: Reject H0 There is heteroscedasticity, see appendix. Therefore, according to Hoechle, D. (2006). when autocorrelation occurs, the way to deal with it is to use (ro) robustness. For Model 3. Because the Prob value > $Chi^2 = 0.8427 > 0.05$, Fail to reject H_0 There is no evidence of heteroscedasticity, see attachment. For Model 2, it has passed the classical assumption test including Heteroscedasticity because it uses a random effect model with GLS.

The classical assumption test results for the model in this study indicate the presence of multicollinearity, heteroscedasticity, and autocorrelation. This study also identified the presence of inter-group dependence after the cross-sectional dependence test. To address the issue of the absence of blue in this panel model, it is important to correct the standard errors. This ensures the validity and reliability of the regression estimation findings. Hoechle, D. (2006) developed a method to overcome the absence of blue data in the model by designing robust standard errors for panel regression with cross-sectional dependence in Stata. Simulations were conducted to evaluate the effectiveness of this approach compared to other methods that do not account for cross-sectional dependence. The findings show that the method proposed by Hoechle (2006) effectively overcomes the limitations of non-blue panel data models, especially in scenarios involving cross-sectional interdependence. This study uses the standard errors proposed by Hoechle (2006).

4.7. Selecting the Most Appropriate Regression Model

Three important tests must be performed to find the best regression model for panel data analysis: Chow Test, Hausman Test, and Lagrange Multiplier Test. These tests help determine which of the three models-a random effects model, a fixed effects model, or a general effects model-is best to use.

Table.4.4. Specification Test Results Pertaining to Model 1

Chow Test (Prob >F)	Lagrangian Multiplier Test (Prob > chibar2)	Hausman Test (Prob > chi2)	Best Model
0.0270	0.0000	0.0077	Fixed Effect Model

Data analysed by the author

Based on the specification test results in table 4.3, the panel regression model selection is carried out through three stages of testing, namely the Chow

Test, Lagrange Multiplier Test, and Hausman Test. The Chow Test results show a Prob value of 0.0270 (<0.05), so the H0 hypothesis is rejected and the Common Effect model is not suitable compared to the fixed effect model. Furthermore, the Lagrangian Multiplier Test was conducted with a result of 0.000 (<0.05), so that the H0 hypothesis was rejected and the Common Effect Model was not suitable compared to the Random Effect Model. Furthermore, the Hausman Test was conducted to select the best model between the Fixed Effect Model and the Random Effect Model with a result of 0.0002 (<0.05), so the hypothesis rejects H0 and the Random Effect Model is not suitable compared to the Fixed Effect Model.

The Fixed Effects Model seems appropriate for all 17 country cases as it is likely that country differences in fixed characteristics (i.e., governance system, policy climate, past infrastructure, and unobserved social values that affect EV adoption) can be found. The FEM corrects for these effects by removing characteristics that do not change over time, which is well suited to capture within-country variation over time. The large number of countries on which the index is built justifies the assumption that country fixed effects are correlated with the independent variables, implying that the FEM is an appropriate choice. This has been explained by Baltagi (2005) explaining that the Fixed Effect Model is very suitable for use when there is a potential correlation between individual effects and independent variables which can cause bias if ignored.

Table.4.5. Specification Test Results Pertaining to Model 2

Chow Test (Prob >F)	Lagrangian Multiplier Test (Prob > chibar2)	Hausman Test (Prob > chi2)	Best Model
0.0000	0.0000	0.6983	Random Effect Model

Data analysed by the author

Based on the specification test results in table 4.4, the panel regression model selection is carried out through three stages of testing, namely the Chow Test, Lagrange Multiplier Test, and Hausman Test. The Chow Test results show a Prob value of 0.0000 (<0.05), so the H0 hypothesis is rejected and the Common Effect model is not suitable compared to the fixed effect model. Furthermore, the

Lagrangian Multiplier Test was carried out with a result of 0.0000 (<0.05), so the H0 hypothesis was rejected and the Common Effect Model was not suitable compared to the Random Effect Model. Furthermore, the Hausman Test was conducted to select the best model between the Fixed Effect Model and the Random Effect Model with a result of 0.6983 (<0.05), so the hypothesis accepts H0 and the Fixed Effect Model is not suitable compared to the Random Effect Model.

For the group of eleven countries with the highest electric vehicle (EV) penetration, the REM model was used. This group is less heterogeneous, given that they already have well-developed policies and support infrastructure. REM accommodates cross-country variation as a random effect, assuming that country effects are uncorrelated with the independent variables. Therefore, REM is the best choice as it is statistically efficient when entities are more homogeneous and fixed effects are treated as random. This is in line with Siao (2003), who states that REM is more appropriate if the panel entities are relatively homogeneous and the assumption of independence between individual effects and explanatory variables is acceptable.

Table.4.6. Specification Test Results Pertaining to Model 3

Chow Test (Prob >F)	Lagrangian Multiplier Test (Prob > chibar2)	Hausman Test (Prob > chi2)	Best Model
0.0270	0.0000	0.0002	Common Effect Model

Data analysed by the author

Based on the specification test results in table 4.5, the panel regression model selection is carried out through three stages of testing, namely the Chow Test, Lagrange Multiplier Test, and Hausman Test. The Chow Test results show a Prob value of 0.0270 (<0.05), so the H0 hypothesis is rejected and the Common Effect model is not suitable compared to the fixed effect model. Furthermore, the Lagrangian Multiplier Test was conducted with a result of 1.000 (>0.05), so the H0 hypothesis was accepted and the Random Effect Model was not suitable compared to the Common Effect Model. Furthermore, the Hausman Test was conducted to select the best model between the Fixed Effect Model and the Common Effect

Model with a result of 0.0002 (<0.05), so the H0 hypothesis was accepted and the Fixed Effect model and the Model were not suitable compared to the Common Effect Model.

In the group of countries, where electric vehicle (EV) adoption is at a less developed level, a Pooled OLS Model is estimated, as the sample size is very small (only 6 countries) and the inter-entity variation of individual effects is low. Otherwise, the estimates would be unstable or overfit when applying fixed or random effects modelling. CEM is a reasonable procedure as it adjusts for common averages across time and countries without regard to individual effects. This makes sense with early-stage exploration strategies for markets that are just beginning to transition to electric vehicles. Gujarati & Porter (2009) explain that the Common Effect Model can be used if the individual effects between units are not significant or not systematically different.

4.8. Results obtained from FEM,REM,CEM.

Table. 4.7. Results Model 1. Obtained from the Fixed Effect Model

Variable	Coefficient	Std.err	Prob
POLICY	3.948347	0.8017739	0.000***
ln_INCOME	1.5559	0.911799	0.092
ln_INFRA	0.4254387	0.1014773	0.000***
ln_FUEL	0.0439665	0.0790632	0.580
EPI	-0.0244918	0.0186853	0.194
ln_POPUL	130.6455	142.2841	0.361
ln_URBANZ	27.77246	7.849728	0.001***
_cons	-545.0655	413.3722	0.191
N	102	R-Square	0.7969
Countries	17	Prob>F	0.0000***

* p<0.10, ** p<0.05, *** p<0.01

The mathematical formulation of Model 1 is built based on the table above as follows

$$\text{log\_EVS} = 545.0 + 3.948\ \text{POLICY} + 1.555\ \text{log\_INCOME} + 0.425\ \text{log\_INFRA} + 0.043\ \text{log\_FUEL} + -0.024\ \text{EPI} + 130.6\ \text{POPUL} + 27.77\ \text{log\_URBANZ}_i + \varepsilon$$

The table above presents the fixed effects model estimation results for model 1, which includes all 17 countries categorized into two groups of observations: countries with high electric vehicle adoption and countries with developing electric vehicle adoption. Model 1 aims to assess the effect on the uptake of electric vehicles. Statistical testing provides the following results: R-Squared, F-Statistic, and t-Statistic. The coefficient of determination (R^2) is 0.7969, indicating that 79% of the variance in Electric Vehicle Sales is explained by the model, and the remaining 21% is due to external factors not included in the model. The calculated F-statistic value is 0.000, which is smaller than the 5% significance threshold. This indicates that the independent variables in the model together have the ability to explain Electric Vehicle Sales. The model predicts that Electric Vehicle Sales will be -545.0 when all independent and control variables are set to zero. When the independent variables in the model have no effect, the fundamental value of the natural logarithm of Electric Vehicle Sales is -545.0.

The statistical test results show that the variable that has a significant influence on EV_Sales emissions in all countries observed is policy (POLICY) which is shown to have a positive and highly significant influence on electric vehicle adoption, with a regression coefficient of $\beta = 3.948$ and a p value of <0.001. This finding indicates a good correlation between the adoption of government regulations and the 3.95 increase in electric vehicles across the 17 countries studied. The 95% confidence interval for this effect ranges from 2.35 to 5.54 units, thus confirming the strong correlation between government initiatives in policy and increased sales of electric vehicles. For the infrastructure variable (INFRA) also shows a highly significant positive effect, with a coefficient $\beta = 0.425$ and a p value < 0.001, indicating positively that every 1% increase in charging station infrastructure in the 17 countries studied is associated with a 0.43% increase in electric vehicles, this evidence shows the importance of infrastructure in supporting the adoption of electric vehicles in the 17 countries studied.

In addition, the controlling variable Urbanization (URBANZ) also has a significant positive effect, with a coefficient value of $\beta = 27.772$ and a p value <0.001. This shows that a 1% increase in urbanization is closely related to a 27.7% growth in Electric Vehicles in urban areas in 17 countries. On the other hand, there are some variables that do not show a statistically significant effect. Income (INCOME) and Environmental Performance Index (EPI) have p-values of 0.092 and 0.194 respectively, indicating that they do not contribute significantly to

Electric Vehicle Adoption. In addition, fuel consumption (FUEL) and population (POPUL) also showed no significant effect, with p-values of 0.580 and 0.361 respectively.

Table. 4.8. Results Model 2. Obtained from the Random Effect Model

Variable	Coefficient	Std.err	Prob
POLICY	0.2274705	0.0642505	0.000***
ln_INCOME	0.7288537	0.5838029	0.212
ln_INFRA	1.011388	0.1418325	0.000***
ln_FUEL	0.1138765	0.0512287	0.026**
EPI	-0.0125614|	0.0167859	0.454
ln_POPUL	1.429856	6.026664	0.812
ln_URBANZ	0.1029025	0.0850291	0.226
_cons	-11.83355	22.60698	0.601
N	66	R-Square	0.7874
Countries	11	Prob>F	0.0000***

* p<0.10, ** p<0.05, *** p<0.01

The mathematical formulation of Model 1 is built based on the table above as follows

$$log\_EVS = -11.83 + 0.227\ POLICY + 0.728\ log\_INCOME + 1.011\ log\_INFRA + 0.113 log\_FUEL + -0.012\ EPI + 1.429\ POPUL + 0.102\ log\_URBANZ_i + \varepsilon$$

The table above shows the results of model 2 analysis using random effects GLS regression. The table shows the correlation between the independent variables and the dependent variable ln_EVS for 66 observations divided into 11 groups based on country variables. The total R-squared value is 0.8169, which means that the model explains 81.69% of the variation in ln_EVS. The model explains 0.7874 within-group variation and 0.8318 between-group variation. At the 1% level, the Wald chi2(7) statistic of 4386.74 and probability of 0.0000 indicates that the overall model is significant.

The statistical test results show that, the POLICY variable has a coefficient of 0.2274705 ($p < 0.01$), which means that it has a positive and statistically significant effect on ln_EVS. This indicates that government policies have a major effect on the adoption of electric vehicles in the 11 countries with the highest electric vehicle sales by 0.23%. The variable ln_INFRA has a large positive effect (coefficient 1.011388, $p < 0.01$), which means that an increase in the number of charging stations by 1% can increase the use of electric vehicles by 1.03% in the 17 countries studied. The ln_FUEL variable has a positive value of 0.1138765 (p <

0.05), which means that it has a statistically significant but small effect. For example, a 1% increase in oil prices is expected to make 0.12% more people buy electric cars.. On the other hand, the EPI variable has a negative value of -0.0125614 ($p > 0.05$), which means it is not statistically significant. Two control variables, ln_POPUL and ln_URBANZ, have significant positive coefficients (1.429856 for ln_POPUL and 0.1029025 for ln_URBANZ; $p < 0.01$), which means that population and urbanization have a positive effect on electric car adoption in 11 countries. The variable ln_INCOME does not have a large influence (coefficient = 0.7288537, $p > 0.05$).

Table. 4.9. Results Model 3. Obtained from the Common Effect Model

Variable	Coefficient	Std.err	Prob
POLICY	1.861784	0.4312458	0.000***
ln_INCOME	1.58803	1.192812	0.195
ln_INFRA	0.9844546	0.1313708	0.000***
ln_FUEL	0.2106178	0.2197542	0.347
EPI	0.0499058	0.03897	0.212
ln_POPUL	1.177026	0.3974619	0.006***
ln_URBANZ	-3.116364	1.489845	0.046**
_cons	-27.68195	12.29766	0.033**
N	36	R-Square	0.8052
Countries	6	Prob>F	0.0000***

* p<0.10, ** p<0.05, *** p<0.01

The mathematical formulation of Model 1 is built based on the table above as follows

$$\text{log\_EVS} = -27.68 + 1.861\ \text{POLICY} + 1.588\ \text{log\_INCOME} + 0.984\ \text{log\_INFRA} + 0.210\ \text{log\_FUEL} + 0.049\ \text{EPI} + 1.177\ \text{POPUL} + -3.116\ \text{log\_URBANZ}_i + \varepsilon$$

Using 36 observations divided into 6 groups based on country variables, the linear regression analysis provides an estimate of the relationship between the independent factors and the dependent variable ln_EVS. The large $F(6, 26)$ of the model, with a probability of less than 0.05, indicates that the model as a whole has strong explanatory power. The R-squared value of 0.8052 indicates that the independent factors of the model explain 80.52% of the variation in ln_EVS. The Root MSE value of 0.91329 indicates the average error rate of the model.

With a 99% confidence level, the statistical test shows that the policy variable (POLICY) has a statistically significant positive effect, as indicated by the regression coefficient of 1.862 ($p < 0.01$). This means that policy implementation is associated with an increase in ln_EVS by 1.862 units. The infrastructure variable (ln_INFRA) has a very strong positive influence, with a coefficient of 0.984 ($p < 0.01$). This means that every 1% increase in the value of infrastructure, such as charging points, the use of electric cars increases by 0.984%. With a coefficient of 1.177 ($p < 0.05$), the population variable (POPUL) acts as a control variable and provides a large positive input at the 95% confidence level. This suggests that as the population increases, the growth value of electric vehicle adoption also increases. On the other hand, the control variable urbanization (ln_URBANZ) has a significant negative effect at the 95% confidence level, with a coefficient of -3.116 ($p < 0.05$). This means that as urbanization increases, ln_EVS decreases. On the other hand, many factors do not have a statistically significant effect. With p values of 0.195 and 0.347 respectively, the factors income (ln_INCOME) and fuel use (ln_FUEL) are not significantly related to ln_EVS. With a p value of 0.212, the environmental performance index (EPI) also has no major influence on ln_EVS.

4.9. Discussion

4.9.1. The Effect of Policy on Electric Vehicle Adoption

The regression Estimates from the three panel regression models show that all policy variables have a positive and significant impact on electric vehicle (EV) adoption rates. In Model 1 (presented for 17 sample countries), the presence of an electric vehicle policy has a significant impact on the probability of electric vehicle adoption/sales. This result provides evidence that the presence of policies is a signal to the market and consumers. In Model 2, which consists of 11 leading electric vehicle adopter countries, the role of policy is still statistically significant. This validates the hypothesis that at least countries with high adoption rates have a strong policy environment, whether in the form of financial incentives, national electrification targets or public infrastructure provision. In contrast, in Model 3 (which includes 6 countries with countries with emerging electric vehicle adoption), the policy variables still have a positive effect, albeit to a lesser extent. This suggests that policy interventions have played an important role in the adoption of electric vehicles.

These results illustrate the pivotal role of the state as a key institutional actor driving Electric transportation transformation. Such policy support not only affects the economic aspects through economic incentives, but also influences a significant component of beliefs regarding the feasibility and urgency of emerging electric vehicles. A supportive policy environment, especially government public policy, can be powerful to shift the behaviour of both consumers and producers towards a low-emission technology: electric vehicles.

This is in line with the principle of institutional theory DiMaggio P, Powell W. (1983) states that public policies and formal rules can influence the way organizations and people act. This finding is consistent with the theory. In this situation, policies such as tax breaks, subsidies, or laws for greener cars create institutional forces that encourage the switch to electric vehicles. It also shows how government policies can be an external factor that influences choices about what technologies to use.

Government regulatory policy is the most important external factor affecting the penetration of electric vehicle adoption, as the world's three largest electric vehicle markets by sales volume, China, the US and Norway, have documented the biggest lessons on how government policy affects electric vehicle adoption trends. China has a strong grip on the electric vehicle market as its government issued numerous regulations on making the use of electric vehicles mandatory. China sells more than 6.8 million units by 2022. Draft regulations on electric vehicles have been in place since 2009 in China - and still are, supporting financial policies for the industry and policies for consumers, with policies investing heavily in the construction of charging stations and the growth of the battery industry.

The draft government regulation also contributes to greater availability of electric vehicles by reducing production costs, increasing adoption, and facilitating the delivery of large quantities of goods to distant markets. The government's concentration on electric transportation demonstrates continued efforts to address environmental and energy security concerns despite the use of coal-based power sources. Experiences from the seventeen countries studied suggest that focused government policies - including subsidies, infrastructure, and fuel economy standards - will be necessary to get more electric vehicles on the road. Success depends on factors such as the nature of each country's energy supply and economic system, so a customized approach is required.

Things with research conducted by Ehsan, F., et al, I. (2024). In their journal entitled; “Assessing policy influence on electric vehicle adoption in China: An in-depth study” this research study thoroughly illustrates the substantial and beneficial influence of two different categories of electric vehicle (EV) policies, namely financial policies and preferential policies, on consumers' intention to adopt EVs, using an enhanced and elaborated version of the Theory of Planned Behaviour (TPB). The findings of the survey analysis show that financial policies and preferential policies for electric vehicles substantially influence customer sentiment and are strongly correlated with EV usage plans.

Although the findings show a strong positive effect of the policy variable, it is worth mentioning that in this article, the policy variable is captured by a dummy code (1 if yes, 0 if no). Of course, this is an idealization and, as such, a methodological limitation that should be acknowledged. EVPs from different countries have very different forms, shares, and phases, with forms ranging from purchase subsidies, tax credits, bans on combustion engine cars, or provision of charging points. Therefore, the positive impact observed here represents the average effect of the existence of the policy in general, and not the effect of a specific type of policy. The “1” in this variable can represent a very strong policy in one country and a symbolic policy in another. Therefore, the findings should be interpreted in light of the measurement method. For future research, it is recommended that the policy variable be measured in a more nuanced way, for example by developing an electric vehicle policy index that is able to comprehensively cover fiscal, regulatory and institutional aspects. This could allow for a more refined assessment of the comparative impact of different types of policies and improve the precision of explanations for electric car developments at the global and regional levels.

These findings reinforce the idea that public policy is a key driver of electric vehicle adoption. However, the binary policy measures used in this study may oversimplify the diversity and strength of electric vehicle policies across countries. Future studies should consider developing a more detailed electric vehicle policy index to capture the true impact of various policy instruments.

4.9.2. The Effect of Infrastructure on Electric Vehicle Adoption

The charging infrastructure variable (Charging_Station) shows a positive and statistically significant effect on EVs which is the regression result of all models in this study. In Model 1, which includes 17 countries, there is a positive and significant relationship between the expansion in the number of charging stations and adoption (represented by EV sales). This result suggests that the presence of facilities has an important influence on the acceptance of EV technology. This resilience is also observed in Model 2, which includes the 11 countries with the highest EV adoption rates. Countries in this group have generally led national policies to develop EV infrastructure such as fast charging station networks and public transportation systems. A large amount of convenient infrastructure reinforces consumer readiness and lowers adoption resistance. In Model 3 (adding 6 countries with emerging electric vehicle adoption), infrastructure is still a significant influencing factor. This suggests that charging infrastructure is a significant driver of adoption even in the early days of the market, but only to a certain extent.

In general, it verifies that the existence of charging infrastructure in each country is a very important prerequisite in consumers' decision to purchase an electric vehicle (EV). So as long as users have ample access to EV charging stations, the “range anxiety” that users have always felt is less of a risk. In contrast, lack of infrastructure will be a major obstacle, especially for less experienced customers and in densely populated urban areas.

These results can be interpreted in the context of the Diffusion of Innovations Theory (Rogers, 2003). Suitability and complexity are among the dimensions measured for innovation adoption. Charging infrastructure increases the “suitability” of electric vehicles (EVs) for everyday mobility needs and the “complexity” or technical integration required to use such vehicles. Thus, the stronger the structure, the faster IT, such as EVs, can be accepted and spread in society.

The fact that this approach works in China is a testament to that. The government is not only using financial incentives but also spending a lot of money to create a functioning network of charging stations. China has the most charging locations of any country in the world today, which makes sense as it is the largest electric car market in the world. On the other hand, India has a big problem with its infrastructure. The electric vehicle (EV) market is growing fast, but there are not many charging stations, especially in places that are not cities. The Indian government wants the public and private sectors to work together to expand the charging network, but it is still not large enough to support the fair deployment of electric vehicles.

The importance of infrastructure in increasing the adoption of electric vehicles is also stated in the research of Mastoi, M. S., et al. (2022), entitled "An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends “The prevalence of electric vehicles is expected to rise sharply over the next decade as technological advances, charging infrastructure and grid connectivity become essential. This article presents the debate on electric vehicle charging infrastructure and grid integration. In addition, electric vehicles and their charging infrastructure must comply with standardized regulations globally to increase market acceptance.

These findings have important implications: strategies for electric vehicle (EV) infrastructure deployment should be one of the key success factors in roadmaps towards energy transition and sustainable mobility. Governments, especially in low-adoption countries, should not only provide incentives for the purchase of these vehicles but also encourage investment in charging infrastructure in urban and semi-urban areas. The long-term success of the transition to electric vehicles will largely depend on a holistic ecosystem of support, and charging infrastructure is a key cornerstone of such an ecosystem. The speed of its expansion will increase significantly through cooperation between the central government, local governments, and the private sector, as well as the expansion of accessibility.

Charging infrastructure has proven to be an important driver in the adoption of electric vehicles. Without adequate and accessible charging stations, even large financial incentives will not be enough. Lessons from countries like China emphasize that infrastructure development and policy incentives must go hand in hand to drive a meaningful electric vehicle transition.

4.9.3. The Effect of Socio-Economics Factor on Electric Vehicle Adoption

The regression analysis An investigation into socio-economic factors reveals that the magnitude of their influence is not uniform across all measurement models. None of the three factors identified-EPI, Fuel Price, and Income per Capita-have a statistically significant positive impact on EV adoption in either Model 1 (all 17 countries), or Model 3 (6 countries with emerging adoption development). However, fuel price has a positive and significant effect in Model 2, but the EPI and income per capita variables do not have a significant positive impact. These findings provide evidence that in countries with high EV adoption, higher fuel prices may encourage consumers to purchase EV as a more affordable operating option.

There are two findings in this study. First, socio-economic issues in general are not the biggest factor behind electric vehicle adoption (in particular, in countries that are at an early or intermediate stage in transitioning to low-emission vehicles). This is because environmental awareness or purchasing power may not be enough to seriously change consumer preferences given the lack of incentive policies and supportive infrastructure.

Second, the significant positive effect of fuel price in Model 2, but not in Models 1 and 3, is the main comparative finding. This suggests that fuel prices should be taken into account more in countries with high EV adoption, compared to developing countries. This difference can be explained in various ways:

1. TCO (Total Cost of Ownership) is now a significant issue in developed countries where purchasing decisions are based on common sense and long-term cost-effectiveness. Fuel prices are higher, making it more economical than ever to drive an EV using clean energy.

2. In poorer fuel-dependent countries, government subsidies make gasoline and diesel prices less volatile and the economic case for switching to EVs less compelling. Overall, weak purchasing power makes the initial cost of EVs a heavy barrier, regardless of whether their efficiency is good in the long run.

The above findings are also corroborated by a study by Sierzchula et al. (2014), which suggests that rising operating costs of conventional vehicles may trigger a switch to electric vehicles, especially in markets that are responsive to energy prices. In contrast, the EPI and INCOME variables remain statistically insignificant. This suggests that high environmental performance scores and increased purchasing power may not inherently provide strong incentives for individuals to use ecologically sustainable solutions. Li et al. (2017) in their global study on factors influencing EV adoption. Although fuel prices may make people more likely to buy EVs in some situations, these results suggest that a comprehensive plan is needed to make the transition to EVs successful. This plan should include policies, infrastructure, and changes in the way people purchase goods.

The results of research by Anastasiadou, K., & Gavanas, N. (2022) found the same results regarding environmental awareness. In their paper aims to identify the key determinants that influence consumer adoption of electric vehicles (EVs), with a focus on private passenger cars. To achieve this objective, a systematic review of recent international literature was conducted to identify drivers and barriers, which were then categorized using the PESTLE (Political-Economic-Social-Technology-Legal-Environmental) approach, the conclusion is that environmental aspects are less important to consumers than anticipated, despite concerns about climate change and the renewable energy transition.

The above findings can also be explained by Theory of Planned Behaviour (TPB), Ajzen, (1991). consumer purchase decisions towards electric vehicles (EVs) are determined by attitudes towards the behaviour, subjective norms, and perceived behavioural control. High fuel prices in developed countries such as these may encourage positive attitudes towards electric vehicles that are perceived to be more efficient and environmentally friendly. In developing countries, on the other hand, such attitudes may not yet be formed due to the economic burden and lack of control in economic purchases.

The analysis of socioeconomic factors in this study shows that per capita income, the Environmental Performance Index (EPI), and fuel prices do not consistently influence electric vehicle (EV) adoption across all models. Specifically, per capita income and the EPI do not exhibit statistically significant positive effects on EV adoption, in either the comprehensive model (Model 1) or the emerging market model (Model 3). These results suggest that EVs in this study are not strongly categorized as normal goods, as increased income does not automatically increase EV adoption. However, there is no evidence that EVs behave as inferior goods or Giffen goods, as higher income does not decrease demand. Specifically, in Model 2 (countries with high EV adoption), fuel prices exhibit a positive and significant effect, suggesting that in mature EV markets, higher fuel prices may encourage consumers to switch to EVs as a cost-saving option. This is in line with Mankiw's (2018) empirical findings, which found that demand for conventional goods increases with income, whereas electric vehicles in this study did not show this pattern. However, electric vehicles also did not show the characteristics of inferior goods or Giffen goods, as demand did not decrease with income or increase with price. Therefore, these findings suggest that electric vehicles are more appropriately considered as new technology goods or emerging goods, i.e., a type of good whose adoption is more influenced by market structure and institutional support than income-based demand factors. According to Chen, R., et al. (2023), new goods or emerging goods typically require policy intervention, subsidy schemes, and infrastructure development to reach the initial adoption threshold.

This finding highlights that structural factors such as policy support, infrastructure readiness, and energy prices play a more important role in influencing the adoption of electric vehicles than individual socioeconomic factors alone. This aligns with the findings of Sierzchula et al. (2014) and Anastasiadou & Gavanas (2022), which indicate that factors such as public policy, fiscal incentives, and charging infrastructure are more dominant in driving electric vehicle adoption than income. Therefore, the findings of previous studies reinforce the idea that electric vehicles should be considered a new product, where adoption is determined by structural factors, not just purchasing power.

Given these findings, it is recommended that countries with growing electric vehicle (EV) adoption consider energy price adjustments, including the removal of fossil fuel subsidies and the introduction of carbon/energy taxes. Such countries should also design policies that will reinforce not only the presumed economic value of electric driving but also the awareness of long-term cost efficiency and the availability of low-cost electric vehicle schemes for all.

Socioeconomic factors such as income and environmental concerns do not consistently influence electric vehicle adoption, especially in developing countries. The significance of fuel prices in countries with high adoption rates suggests that long-term cost considerations-such as Total Cost of Ownership-can motivate electric vehicle purchases when structural conditions, such as pricing policies and infrastructure, are favourable.

4.9.4. Control Variable

In this study two control variables that uses, Population and Urbanization, are introduced to improve the analysis model of electric vehicle adoption. The estimation results show that both variables have asymmetric impacts on different country groups. The control variables do not have significantly different effects on electric vehicle sales in Model 2 (in the 11 countries with the highest electric vehicle sales). This suggests that, in countries where the electric vehicle market has reached a certain level of consolidation, population size and level of urbanization are no longer the main drivers. Policy incentives, infrastructure and energy prices "likely play a relatively large role in driving adoption decisions," with mature markets.

In contrast, in Model 3 (which consists of 6 countries with emerging electric vehicle adoption), both control variables are statistically far from irrelevant. This reveals that in the early stages of electric vehicle diffusion, population and urbanization levels have a major influence on the expansion or stagnation of the electric vehicle market.

These results suggest that the electric vehicle (EV) adoption environment shapes the role of demographic factors. In countries with emerging EV adoption

(Model 3), there is safety in numbers, as having a large and diverse PV can also maximize market potential and economies of scale opportunities with actual EV-related equipment manufacturers and service providers. On the other hand, high levels of urbanization are generally associated with higher infrastructure density, electrification, environmental concerns, and transportation efficiency that support EV adoption in urban areas. In contrast, in countries with high adoption rates (Model 2), the EV market has moved beyond the demographic bases of gender, age, education, and income, with the market composition increasingly explained by policy quality, technological innovation, and support systems. This suggests that at a later stage, predictable factors, including population and urbanization, are less relevant as determinants of adoption, given that consumer choices are driven more by the benefits brought by the technology and aspects related to adoption rules.

Based on these findings, it is suggested that countries with emerging EV adoption rates can capitalize on the potential of their demographics-for example, densely populated urban concentrations-to begin the process of gradually building EV ecosystems. City-cantered policies can be a useful start as city residents are more connected and receptive to change faster, and cities with their infrastructure are the best place to start customizing such systems in small steps. Governments should also ensure that as populations grow in strategic locations, this can be followed by the expansion of EV support infrastructure, including charging points and helplines.

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study examines how policy, infrastructure and socio-economic factors such as environmental awareness, income per capita and oil prices, and also adds several control variables including population and urbanization in influencing the adoption of electric vehicles in seventeen countries. The country classification in this study is divided into two groups of country classifications, namely eleven countries with the most electric vehicle adoption and six countries with developing electric vehicle adoption, this grouping is based on the International Energy agency, this is an international organization that focuses on energy issues, including energy security, economic development, and environmental protection.

This study shows evidence that there is a consistent and positive influence of the two main independent variables, namely Policy and Infrastructure. This indicates that the role of government policy products such as tax incentives and investment policies have a major influence on the spread of electric vehicle adoption in the seventeen countries studied. Government policy becomes an external reference for individuals in deciding to buy an electric vehicle. Meanwhile, the availability of infrastructure, namely charging stations, is a major component in supporting the adoption of electric vehicles in general, with the availability of charging stations spread across the country, it will break the Range anxiety of the public in electric vehicle products that they have been worried about so far.

The lack of statistically significant socio-economic variable relationships in almost all country test classifications may be due to the fact that the three variables may have a lag effect, where the influence can only be felt after a certain period of years, which is not captured by the statistical model tested. Furthermore, there may be mediating variables such as the level of environmental education, or specific local policies that are not included in the model, causing socio-economic variables to be insignificant in the estimation results. However, positive results were found for the fuel price variable for testing the classification of countries with the highest adoption of electric vehicles, which indicates that the eleven countries in this classification have begun to consider fuel price conditions by considering buying more efficient and environmentally friendly electric vehicles.

This study found that socioeconomic factors, particularly per capita income, do not have a consistent or significant influence on the adoption of electric vehicles, indicating that electric vehicles cannot be categorized as normal goods. However, electric vehicles also do not exhibit the characteristics of inferior goods or Giffen goods. Instead, the findings highlight that structural factors such as policy support, infrastructure development, and fuel prices play a more decisive role in driving global electric vehicle adoption. In this context, electric vehicles are better viewed as new technology goods or emerging goods, whose market penetration depends more on institutional intervention, fiscal incentives, and the availability of supporting infrastructure, rather than on income-driven demand.

The Diffusion of Innovation, Institutional Behaviour hypothesis is validated across all twelve country objectives and all three country grouping classification models. For the Theory of Plan Behaviour theory the correlation exists, but is not very significant. TPB has a significant impact on the group of eleven countries with the most electric vehicle adoption where TPB is very relevant with positive evidence of fuel prices on electric vehicle adoption.

5.2. Policy Recommendations

5.2.1. Policy Recommendations for Countries with High EV Adoption

The regression output for high electric vehicle adoption countries reveals that charging policies and infrastructure are significantly positively associated with electric vehicle adoptions. Fuel prices also have a positive impact, while the importance of other socio-economic variables (income per capita, Environmental Performance Index (E.P.I.), and control variables (population, urbanization) are not statistically significant :

1. Enhance Existing Policies to Improve Market Efficiency

   The government should maintain and enhance existing policies and measures, including fiscal incentives, tax credits, and emission standards. However, with the high cost of technological and regulatory standards to enable infrastructure to be used across regions, a new push should be made to consolidate them.

2. Focused and Coordinated Infrastructure Expansion

   Even with a relatively high adoption rate, upgrading charging infrastructure across the country (including fast charging outside population centres) will be key to addressing the surge in demand and providing long-term convenience for drivers.

3. Using Energy Costs as a Behavioural Tool

   The positive effects of fuel prices may provide justification for reducing fossil fuel subsidies or increasing carbon taxes that force a change in consumer propensity to use electric vehicles.

4. Emphasize the Vision of Sustainable Development of the Electric Vehicle Ecosystem From now on, policies should change the focus from “promoting adoption” to “sustaining the ecosystem,” respecting the management of used batteries, improving recycling, and integrating electric vehicles into renewable energy systems.

5.2.2. Policy Recommendations for Countries with Emerging EV Adoption

In this category, the two independent variables that have positive and significant effects are policy and infrastructure. Socio-economic variables such as fuel price, EPI, and per capita income have no effect, while the control variables urbanization and population are significant, indicating a positive factor effect in the early stages of adoption **:**

1. Develop Infrastructure in Urban Areas First

   As population and urbanization are key parameters, charging stations should be located in densely populated urban areas, where the demand and potential concentration of electric vehicles (EVs) is greatest.

2. Strengthen Policy Signals and Regulatory Stability

   Policy presence is a powerful medieval approach that has influence in low-income countries. This means in practice that policies do not just exist on paper but translate into reality, for example in the form of incentives, vehicle tax reductions, or credits.

3. Promote and encourage partnership models for financing schemes
   The challenge is that, when purchasing power is limited, one has to develop creative financing mechanisms, such as EV leasing, green credit subsidies, and first buyer bonuses (for early adopters).
4. EV social education and literacy in Urban Areas
   The deployment and education of electric vehicles to the public through community and school-based education programs in urban areas can significantly complement early market development.

5.3. Limitation of Study

This study cannot be separated from several limitations that require researchers to develop further in order to provide more comprehensive and substantial contribution results for academic purposes, regulatory utilization, and policy references. This study does not take into account endogeneity and lag time issues that may exist in panel data regression models, potentially leading to estimation bias and inconsistency. Considerations in future research are to use a more appropriate approach, especially in dealing with the potential influence of endogeneity, in order to produce more reliable results. The use of the independent variable Environmental Awareness may not cover all aspects of environmental awareness and the time series selected is limited, resulting in bias that does not describe other environmental awareness factors in the formation of environmental performance index benchmarks. For further research, it is recommended to be more specific in the measurement of policy variables, such as creating an electric vehicle policy index, which would summarize quantitatively and comprehensively the three dimensions: fiscal, regulatory, and institutional. Such an approach would allow for a more comprehensive analysis of the relative performance among different types of policies, as well as offer a better forecast of the dynamics of electric vehicle deployment at the global and regional levels. The limited availability of the required data is also one of the obstacles faced by the author so that the research time span and the countries studied in this study are relatively few and short.

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APENDIX

Appendix 1 : Descriptive statistic Model 1

Variable	Obs	Mean	Std. dev.	Min	Max
ID	102	9	4.923172	1	17
YEARS	102	2020.5	1.716259	2018	2023
EVS	102	694215.1	2867418	0	2.52e+07
POLICY	102	.9901961	.0990148	0	1
INFRA	102	102311.3	343746.4	0	2700000
EPI	102	60.51324	16.6484	18.9	83.95
FUEL	102	45538.32	19550.76	1918	61713
INCOME	102	33048.06	24957.32	1907.043	108798.5
URBANZ	102	13133.31	28596.78	34.031	83298
POPUL	102	18.44581	1.351761	15.48546	21.08657
ln_EVS	102	10.85905	2.582551	0	17.04421
ln_INCOME	102	9.980976	1.060936	7.553309	11.59725
ln_FUEL	102	10.48499	.9053311	7.559038	11.03025
ln_URBANZ	102	5.513006	2.658986	3.527272	11.33018
ln_POPUL	102	2.912174	.0734275	2.739902	3.048636
ln_INFRA	102	9.248004	2.655499	0	14.80876

Appendix 2 : Descriptive statistic Model 2

```
Panel variable: ID (unbalanced)
 Time variable: YEARS, 2018 to 2023
         Delta: 1 unit

. summarize
```

Variable	Obs	Mean	Std. dev.	Min	Max
ID	66	6	3.18651	1	11
YEARS	66	2020.5	1.720912	2018	2023
EVS	66	1060198	3519833	10401	2.52e+07
POLICY	66	1	0	1	1
INFRA	66	157119.2	418281.1	3470	2700000
EPI	66	69.53348	11.74698	28.4	83.95
FUEL	66	45822.23	19440.64	1918	61713
INCOME	66	47131.41	19781.97	9905.406	108798.5
URBANZ	66	20261.63	33533.75	70.438	83298
POPUL	66	18.08475	1.384438	15.48546	21.06853

Appendix 3 : Descriptive statistic Model 3

```
. summarize
```

Variable	Obs	Mean	Std. dev.	Min	Max
ID	36	3.5	1.732051	1	6
YEARS	36	2020.5	1.732051	2018	2023
EVS	36	23247.25	48944.61	0	254766
POLICY	36	.9722222	.1666667	0	1
INFRA	36	1830.139	2669.998	0	10900
EPI	36	43.97611	10.43264	18.9	60.7
FUEL	36	45017.83	20017.42	4918	61713
INCOME	36	7228.585	3311.161	1907.043	13790.02
URBANZ	36	64.72508	18.54685	34.031	87.788
POPUL	36	19.10775	1.008417	18.08347	21.08657

Appendix 4 : Multicollinearity Test Model 1

. vif,uncentered

Variable	VIF	1/VIF
INCOME_c	5.77	0.173174
EPI_c	5.24	0.190735
POPUL_c	2.36	0.424273
INFRA_c	1.33	0.752115
ln_URBANZ	1.13	0.883541
FUEL_c	1.06	0.946200
POLICY_c	1.05	0.948353
Mean VIF	2.56	

Appendix 5: Multicollinearity Test Model 2

. vif,uncentered

Variable	VIF	1/VIF
URBANZ_c	8.20	0.121966
INCOME_c	7.81	0.128011
EPI_c	5.97	0.167604
FUEL	3.95	0.253233
POPUL_c	3.59	0.278412
INFRA	2.69	0.371323
POLICY_c	1.14	0.874027
Mean VIF	4.59	

Appendix 6 : Multicollinearity Test Model 3

. vif,uncentered

Variable	VIF	1/VIF
_cons	16.02	0.062438
FUEL	7.17	0.139433
POPUL_c	5.83	0.171527
URBANZ	4.49	0.222524
INCOME_c	3.15	0.317567
EPI_c	2.22	0.450416
INFRA	2.20	0.455040
POLICY_c	1.10	0.905741
Mean VIF	5.50	

Appendix 7 : Autocorrelation Test Model 1

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,      16) =     28.329
           Prob > F =      0.0001
```

Appendix 8 : Autocorrelation Test Model 3

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,      10) =     11.563
           Prob > F =      0.0068
```

Appendix 9 : Heteroskedasticity Test Model 1

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (17)  =        1212.57
Prob > chi2 =          0.0000
```

Appendix 10 : Heteroskedasticity Test Model 3

```
Breusch–Pagan/Cook–Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of ln_EVS

H0: Constant variance

    chi2(1) =   0.04
Prob > chi2 = 0.8427

.
```

Appendix 11 : Fixed Effect Model (Model 1)

```
Fixed-effects (within) regression               Number of obs     =        102
Group variable: ID                              Number of groups  =         17

R-squared:                                      Obs per group:
     Within  = 0.7969                                         min =          6
     Between = 0.4367                                         avg =        6.0
     Overall = 0.3350                                         max =          6

                                                F(7, 78)          =      43.73
corr(u_i, Xb) = -0.9997                         Prob > F          =     0.0000

                                   (Std. err. adjusted for 17 clusters in ID)
```

ln_EVS	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
POLICY	3.948347	.8017739	4.92	0.000	2.352137	5.544556
ln_INCOME	1.5559	.911799	1.71	0.092	-.2593522	3.371153
ln_INFRA	.4254387	.1014773	4.19	0.000	.223413	.6274645
ln_FUEL	.0439665	.0790632	0.56	0.580	-.1134362	.2013691
EPI	-.0244918	.0186853	-1.31	0.194	-.0616914	.0127077
ln_POPUL	130.6455	142.2841	0.92	0.361	-152.6203	413.9113
ln_URBANZ	27.77246	7.849728	3.54	0.001	12.14486	43.40007
_cons	-545.0655	413.3722	-1.32	0.191	-1368.026	277.8953
sigma_u	79.130636					
sigma_e	.66210771					
rho	.99992999	(fraction of variance due to u_i)				

F test that all u_i=0: F(16, 78) = 6.73 Prob > F = 0.0000

Appendix 12 : Random Effect Model (Model 2)

```
Fixed-effects (within) regression               Number of obs     =        102
Group variable: ID                              Number of groups  =         17

R-squared:                                      Obs per group:
     Within  = 0.7969                                         min =          6
     Between = 0.4367                                         avg =        6.0
     Overall = 0.3350                                         max =          6

                                                F(7, 78)          =      43.73
corr(u_i, Xb) = -0.9997                         Prob > F          =     0.0000
```

ln_EVS	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
POLICY	3.948347	.8017739	4.92	0.000	2.352137	5.544556
ln_INCOME	1.5559	.911799	1.71	0.092	-.2593522	3.371153
ln_INFRA	.4254387	.1014773	4.19	0.000	.223413	.6274645
ln_FUEL	.0439665	.0790632	0.56	0.580	-.1134362	.2013691
EPI	-.0244918	.0186853	-1.31	0.194	-.0616914	.0127077
ln_POPUL	130.6455	142.2841	0.92	0.361	-152.6203	413.9113
ln_URBANZ	27.77246	7.849728	3.54	0.001	12.14486	43.40007
_cons	-545.0655	413.3722	-1.32	0.191	-1368.026	277.8953
sigma_u	79.130636					
sigma_e	.66210771					
rho	.99992999	(fraction of variance due to u_i)				

F test that all u_i=0: F(16, 78) = 6.73 Prob > F = 0.0000

Appendix 13 : Common Effect Model (Model 3)

```
Linear regression                               Number of obs     =         34
                                                F(6, 26)          =          .
                                                Prob > F          =          .
                                                R-squared         =     0.8052
                                                Root MSE          =     .91329
```

ln_EVS	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
POLICY	1.861784	.4312458	4.32	0.000	.9753457	2.748223
ln_INCOME	1.58803	1.192812	1.33	0.195	-.8638305	4.039891
ln_INFRA	.9844546	.1313708	7.49	0.000	.7144181	1.254491
ln_FUEL	.2106178	.2197542	0.96	0.347	-.2410933	.662329
EPI	.0499058	.03897	1.28	0.212	-.030198	.1300097
POPUL	1.177026	.3974619	2.96	0.006	.3600313	1.994021
ln_URBANZ	-3.116364	1.489845	-2.09	0.046	-6.178785	-.0539438
_cons	-27.68195	12.29766	-2.25	0.033	-52.96014	-2.403748