Electric vehicle adoption and its impact on the environment and fossil fuel consumption in the context of Maharashtra, India

A thesis submitted to the
UPES

For the Award of
Doctor of Philosophy
in
Management

By
Pabitra Kumar Das

June 2025

Supervisor
Dr Mohammad Younus Bhat



Department of Management-Power
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DECLARATION

I declare that the thesis entitled **"Electric Vehicle Adoption and its Impact on the Environment and Fossil Fuel Consumption in the Context of Maharashtra, India"** has been prepared by me under the guidance of **Dr. Mohammad Younus Bhat**, Associate Professor, Department of Economics, School of Business, UPES, Dehradun, Uttarakhand (Supervisor).

No part of this thesis has formed the basis for awarding any degree or fellowship.



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CERTIFICATE

I Certify that Mr. Pabitra Kumar Das prepared his thesis entitled, **"Electric Vehicle Adoption and its Impact on the Environment and Fossil Fuel Consumption in the Context of Maharashtra, India"** under my guidance for the award of a Ph.D. degree in Management from UPES. He has carried out his work at school of Business, UPES, Dehradun, India.

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ABSTRACT

India’s motor vehicle industry is renowned in the world due to the fact the motor vehicle is one of the major transportation mediums, large scale production of motor vehicles and its sales within and outside India. India is a big nation as far as automobile industry is concerned. India held third in automobile sales in the world. In automobile production it is fourth in the world. As per SIAM annual report 2024, India’s automobile vehicle production in FY 2024 is approximately 28 million units. Total revenue generated by different categories of vehicles currently represents a significant portion of India’s GDP. This industry is responsible for providing employment to a large number of people, both directly and indirectly, according to IBEF data. The automobile sector's rapid expansion is instrumental for boosting Indian economy by creating numerous job opportunities.

Automobile emissions, global warming, Ozone layer depletion, Climate change and energy security issues compelled the developed countries to search for alternate technologies of road transport which will be free from these issues. Electric vehicles, due to zero tail emission, low cost & quite operation and energy efficient nature, might be the answer to tackle above concerns. However, the growth of electric vehicles depends on how the present challenges like high price, low range, charging infrastructure etc. associated with this type of vehicle are taken care of.

Maharashtra holds share of approximately 10% of India’s cumulative automobile vehicle stock Similarly, Maharashtra has a share of approximately 11% of India’s cumulative electric vehicle stock. Maharashtra accounts for 10% of the country’s GHG emission. The motor vehicle sector in Maharashtra has a share of 12% carbon dioxide emission in the state (2021-2022). In Maharashtra, the transport sector has a large contribution on carbon-dioxide emissions and fossil fuel consumption. Despite government incentives and growing knowledge of environmental problems, the embracement rate of electric vehicles remains low. This slow adoption impedes progress toward environmental goals, such as lowering air adulteration and reliance on non-

renewable energy sources, both critical for sustainable development in Maharashtra. Businesses, policymakers, and society at large struggle to understand and address the barriers to EV adoption, such as high upfront costs, inadequate charging infrastructure, limited consumer awareness, and the uncertain effect of EVs on energy demands and on the environment.

Various incentives, subsidies, tax rebates have been declared by central as well as by various state govts. Despite the government's aggressive plans and policies, the on-ground EV sales have not picked up momentum. Only some good results have been seen in the two-wheeler and e-rickshaw segments. Although automotive OEMs are slowly taking steps towards EVs, the speed may not match government deadlines and present automotive market growth. According to the findings, EVs and conventional vehicles are both part of the automotive sector. However, the implementation of the EV plan will have some impacts on the Indian automotive industry. With a critical evaluation of the research in the field of electric vehicles, it has been observed that there is very little research work conducted on the correlation between EVs and motor vehicle industry in India. Insufficient exploration of consumer preferences and attitudes towards EV adoption across Maharashtra's diverse socio-economic landscape has been observed from literature review. It is also found from various research studies that very limited empirical data exists on the real-world impact of EV adoption on emissions reduction in Maharashtra, with a lack of longitudinal studies Scarcity of comprehensive assessments of EV adoption's impact on fossil fuel consumption in Maharashtra, including full lifecycle found from literature review.

Accordingly three research objectives were framed to bridge the research gaps. These are research objective I: To analyze factors influencing the adoption intention of electric vehicles in Maharashtra, research objective II: To assess the impact of EV adoption in terms of carbon emission reduction in Maharashtra, and research objective III: To evaluate the impact of EV adoption on fossil fuel consumption in Maharashtra.

For research objective I, Extended Theory of Planned Behavior has been applied to evaluate electric vehicle purchase intention. In the present study the

determinants used are attitude, subjective norms, perceived behavioral control, environmental concern, technological factor and policy support.

Comparative life cycle assessment concept has been used to achieve research objective II. Carbon emissions occurred in complete life cycle of IC engine vehicle and electric vehicle have been assessed separately and then total car bon emission by both type of vehicles are compared. Accordingly net carbon emission reduction due to adoption of electric vehicle is assessed. Functional unit considered for life time distance covered by a vehicle in Km. Four types of vehicle considered here i.e., two wheelers, three wheelers, car and bus.

To assess the impacts of EV adoption in Indian automotive sector in terms of fossil fuel requirement. The Comparative Life Cycle Assessment approach has been used in this case also.

To evaluate the impact of various cost factors, the life cycle cost (LCC) of IC engine and battery electric vehicles such as two-wheelers, three-wheelers, car and bus are assessed here.

A questionnaire survey has been conducted among the driver/user of related EV and ICE vehicles. The data related to usage has been gathered based on survey methods and balance data has been gathered from secondary sources like research articles, journals, government and private web site. The responses are analyzed using the LCA model concept. Necessary calculations have been carried out with the help of MS excel. Non-probability convenient sampling technique is used due to low population of EV user and for ease of data gathering.

The present study has been conducted on every type of IC engine driven vehicle and electric powered vehicle sector like two -wheeler, three-wheeler, car and bus etc. All types of electrically powered vehicles are considered due to a smaller number of availabilities of these types of vehicles in India. The geographical location has been covered the complete Maharashtra state in India. The current study gathers data from both ***primary data sources*** *and* ***secondary data sources***.

A questionnaire survey has been conducted among the driver/user in Maharashtra, India of related EV and ICE vehicles. Survey was carried out in various places of Maharashtra . 682 vehicles across all categories have been surveyed.

Diagnostic tests such as normality, sampling adequacy, common method bias, total variance, indicator reliability, internal consistency reliability, convergent validity, discriminant validity, robustness check have been carried out. It is concluded from SEM result that selected model is overall fit and all hypotheses are supported. Environment concern factors, technology factors and government policy measures factors comprehensively show customers EV adoption intention in Maharashtra. People believes adopting EV will reduce vehicular emission and stop further damage to air quality and climate at a large. Battery life, battery technology, range, maintenance and overall performance of EV are important factors.

The results show that over their entire life cycle, BEV two-wheeler vehicles emit 34% less CO_2 than ICE two-wheeler vehicles. The BEV three-wheeler vehicle emits 72% less CO_2 than the ICE three-wheeler in its entire life cycle. Similarly, BEV car emit 35% less CO_2 than ICE cars in their entire life cycle. Whereas a BEV bus emits 7% more CO_2 than an ICE bus in its entire life cycle. ICE two-wheelers, three-wheelers, cars, and buses need petrol to the tune of 1560 L, 5540 L, and 4033 L in their entire lives. ICE Bus does not need petrol. Similarly, ICE two-wheelers, three-wheelers, cars, and buses need diesel to the tune of 1000 L, 10500 L, 8300 L, and 255 K L in their entire lives. BEV two-wheelers, three-wheelers, cars, and buses need coal to the tune of 980 kg, 2750 kg, 5400 kg, and 214 tonnes in their entire lives than ICE two-wheelers, three-wheelers, cars, and buses. The benefit of EV adoption was found as a total lifetime savings of INR 203,105, INR 1,064,984, and INR 631,857 for EV two-wheelers, three-wheelers, and cars, respectively. Currently, there is a lifetime loss of INR 66,715.14 for EV buses. Although BEVs do not consume petrol or diesel, the electrical energy used by BEVs comes from fossil fuel. It implies GHG emissions and energy security (petroleum and coal reserves) are not to be

overcome with the adoption of BEVs unless electrical energy comes from clean sources such as solar, wind, hydro, sea waves, etc.

This study combines the Theory of Planned Behavior and Life Cycle Assessment to explore EV adoption, offering a new framework for future research. The empirical formula developed for fossil fuel requirements is widely applicable, opening new research opportunities. The study paves opportunities for local businesses and startups in EV manufacturing, battery recycling, renewable energy integration, EV-friendly infrastructure, such as charging stations and battery-swapping facilities.

The study will help policymakers to make policy for residential societies and commercial buildings to install free PV panels for all types of charging facilities, create EV-only zones in high-pollution urban areas to encourage cleaner transportation, and create infrastructure development progress, such as dedicated EV parking and charging zones to encourage EV adoption. The study findings will guide general public to induct low running cost electric vehicles having lower local air pollution levels that lead to a decrease in respiratory diseases. The study will encourage researcher to work on recycling and proper disposal of EV batteries to ensure sustainability.

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
ANOVA	Analysis of Variance
BEV	Battery Electric Vehicle
BMS	Battery Management System
BS	Bharat standard
CV	Conventional Vehicle
DSO	Distribution System Operator
EIA	International Energy Agency
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCEV	Fuel Cell Electric Vehicle
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse gas
HOV	High occupancy vehicle
ICE	Internal combustion Engine
Li-ion	Lithium-ion battery
OEM	Original Equipment Manufacturer
PHEV	Plug-in hybrid Electric Vehicle
RE	Renewable Energy
SPSS	Statistical Package for Social Sciences
TPB	Theory of Planned Behavior
UNFCCC	United Nation Framework Convention on Climate Change
V2B	Vehicle to building

Chapter 1
Introduction

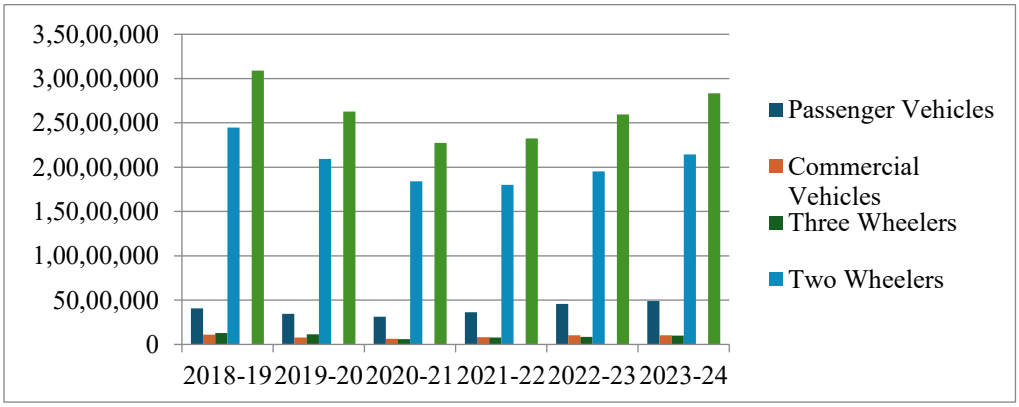
CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

Motor vehicle industry of India is quite large in size and it is renowned in the world. Prior to 1975, there were 3 or 4 companies in India that produced various types of motor vehicles. Vespa and Lambrate were renowned for their two-wheelsers, while Tata Motors and Ashok Leyland were known for producing commercial vehicles. Over the past thirty years, the automobile sector has seen significant growth. Presently, India holds third position in motor vehicle sales and fourth position in motor vehicle production across the world. (Wikipedia Automotive Industry in India) Almost all major global motor vehicle producing brands, like Suzuki, Hyundai, Ford, and Volvo, have set up production facilities in India.

India's cumulative automobile stock is approx. As per SIAM annual report 2024, India's automobile vehicle production in FY 2024 is million units (see Fig.1.1). The total revenue generated by different categories of vehicles currently represents a significant portion of India's GDP. This industry is responsible for providing employment to a large number of people, both directly and indirectly, according to IBEF data. The automobile sector's rapid expansion is instrumental for boosting Indian economy by creating numerous job opportunities. However, it has also exerted considerable effect on environmental contamination, contributing to air impurity and worldwide temperature rise. The gradual reduction of fossil fuel stock and its continuous trend of price increases are also major threats to the sustainable growth of the automobile sector.

Figure 1.1: Indian Automobile Sector Production (in Units)



Source: SIAM DATA

In metropolis of India, air impurities like solid particles, liquid droplets, sulfurous anhydride, laughing gas, nitric oxide, nitrogen dioxide, nitrogen trioxide, carbon oxide and trioxigen frequently surpass the "National Ambient Air Quality Standards" ("NAAQS") (Uslu and DemiRel, 2022). The primary sources of air pollution are identified as motor vehicles, its productions and industrial activities, building works, dust particles, and the burning of solid organic matter (Uslu and DemiRel, 2022). Emissions from conventional engine vehicles are the major shareholder to air contamination (Abhyankar et al., 2017; Abma et al., 2019). These vehicular emissions can originate from operational discharge gases, mix of solid and liquid outflows during operation. Quality of outflow influences kind of solid particles and vaporous discharged into air (Abotalebi et al., 2015). The presence of solid particles and vaporous stuff in the aerophere poses numerous risks on wellbeing of human (Abhyankar et al., 2017). "Mobile Source Air Toxics" ("MSAT") discharged at the time of running outflow emissions may create numerous health issues, comprising congenital abnormalities and bad consequences on the renal system, respiratory system, and sense organs (Abotalebi et al., 2015). Outflow from operational discharge and non-discharge sources have large contributions of pulmonary diseases, pulmonary tissue problems, malignant tumor, and untimely mortality (Abhyankar et al., 2017). In its 2014 assessment, the "World Health Organization" ("WHO") ranked capital city of India as one of the top ten global cosmopolis with the very bad environmental contamination (Uslu and DemiRel, 2022).

India is one of the highest emitters of carbon dioxide in the world. The top four emitters, which covered 58% of global emissions, were China (33%), the USA (13%), India (7%), and Russia (5%) according to World Research Institute. The rest of the world contributed 42%. Thus, the greenhouse gas effect is another problem of automobile emissions. In India, vehicle population has increased in several ways, and the road transport sector has become a matter of serious concern due to its carbon dioxide emissions. China is the highest GHG-

producing country in the world. The USA, Russia, and Japan are major global contributors to GHG.

Global warming due to GHG is a major threat to the earth. The continuous increase in the earth's surface temperature has put a question mark on the survival of mankind. Rising water level affected by the thermal effect, the dissolving of glaciers and frozen water are the other effects. The global recognition of climate change has led to significant actions, such as the signing of "United Nations Framework Convention on Climate Change" ("UNFCCC") by 194 countries during May 2011. Scientists worldwide have recommended a 50% reduction in greenhouse gas emissions by 2050 to prevent severe climate change impacts. This pressing issue is being addressed at the United Nations level, with the Paris Agreement being signed by all UN members in 2016. In response to air pollution, the Indian government implemented "Bharat Stage Emission Standards" ("BS") for motor vehicles in 2000, with stricter regulations introduced in 2005 and 2010. By 2017, BS IV standards were to be enforced nationwide, and a transition from BS IV to BS VI norms for all vehicles was planned for 2020, skipping BS V (CPCB data).

The automobile sector is the key element of transportation. Till few years almost of all automobile vehicles were run by fossil fuel. As per the EIA report, of crude oil is consumed by transportation vehicles. In 2017, worldwide car sales were approximately 79 million. Car sales in China, the USA, Japan, and India are 28.88 million, million, million, and 4.01 million, respectively. In 2017, world oil consumption was barrels per day. The USA is the top (oil consumer), followed by the European Union, China, and India. As per the 2017 report, China is the largest automobile market (28.88 million per year), followed by the USA (17.24 million per year), Japan (5.23 million per year), and India (4.01 million per year). India imported $114 billion of crude oil in 2017. This is equivalent to about.

Most of the automobile vehicles are dependent on crude and it is a known fact that fossil fuel reserve is likely to be exhausted being non-renewable in nature. This energy security issue makes major automobile manufacturing countries concerned. Automobile emissions, global warming, Ozone layer depletion, Climate change and energy security issues compelled the developed countries

to search for alternate technologies of road transport which will be free from these issues. Electric vehicles, due to zero tail emission, low cost & quite operation and energy efficient nature, might be the answer to tackle above concerns. However, the growth of electric vehicles depends on how the present challenges like high price, low range, charging infrastructure etc. associated with this type of vehicle are taken care of.

1.1.1. ELECTRIC VEHICLES: ADDRESSING THE CHALLENGES IN THE TRANSPORT SECTOR

Electric vehicles refer to the motor vehicles primarily driven by an electric power train. In the BEVs, the traction battery acts as the primary energy source for propulsion using the electric motors. The PHEVs additionally have a conventional fossil fuel engine which acts as a secondary source of power, usually when the vehicle batteries are depleted. There are several other subsystems such as battery management system, motor controllers, inverters and converters, thermal management system, transmission system, on-board charger, and high voltage cables which work in tandem for optimal performance of the vehicle.

The electric vehicle can be charged through grid electricity, which is generated through energy sources both conventional and non-conventional. The electric vehicles can, therefore, potentially displace the oil demand entirely; thus, mitigating the energy security risks by diversification of energy sources in transportation.

Furthermore, with the use of electric vehicles, the localized emissions from the transport could virtually be reduced to zero. However, the electricity produced in India is coal intensive which leads to emissions at the generation level. With an increasing share of non-conventional energy in electricity grid, these emissions are likely to be reduced. The electric vehicles also offer the flexibility to act as an energy reservoir during periods of excess non-conventional energy production. The energy is fed back to the grid when the electricity demand is at its peak. The electric vehicles show better energy efficiency in comparison to conventional Engine Vehicles. Also, due to a smaller number of moving parts

in electric vehicles, the maintenance requirement is likely to lower. Thus, they have a lower cost of operation and maintenance.

Despite the advantages mentioned above, currently, the electric vehicles in India encounter several technological, social, and economic challenges on the requirement as well as delivery side in addition to the regulatory front. On the supply side, there is limited experience and resistance among the automakers, as the embracement of electric vehicles would potentially lead to a significant shift from established supply chains and past investments in the development of conventional vehicles. Consequently, there are only a limited variety of electric vehicle models commercially available in India.

There are also technological challenges associated with electric vehicles such as extended time required for charging of the battery. Other challenges are comparatively higher battery cost resulting high price of the vehicle and limited distance cover of the vehicle in one time charge. Purchase cost of the vehicle is comparatively higher which is plays an important hindrance to embracement for a price-sensitive consumer in India. Furthermore, the inadequate charging and support infrastructure discourages a potential consumer from the purchase of an electric vehicle. Another major barrier is the deficiency of information among the users about the available electrified vehicles in the trading place.

For the deployment of electrified vehicles, a consensus among many stakeholders such as automakers, component suppliers, fuel suppliers, electricity generation, transmission and distribution companies, state and central governments, consumers, charging equipment manufacturers and service providers, and fleet operators is essential. Since electric vehicle technology is in its initial stages of deployment, even at the global level, the industry is yet to converge on business models which are financially viable. A regulatory framework is essential to improve the feasibility of the business models through promotion of use of curtailed renewable energy for charging of electric vehicles at a low tariff. Thus, reducing operational costs will counterbalance the high capital cost to some extent.

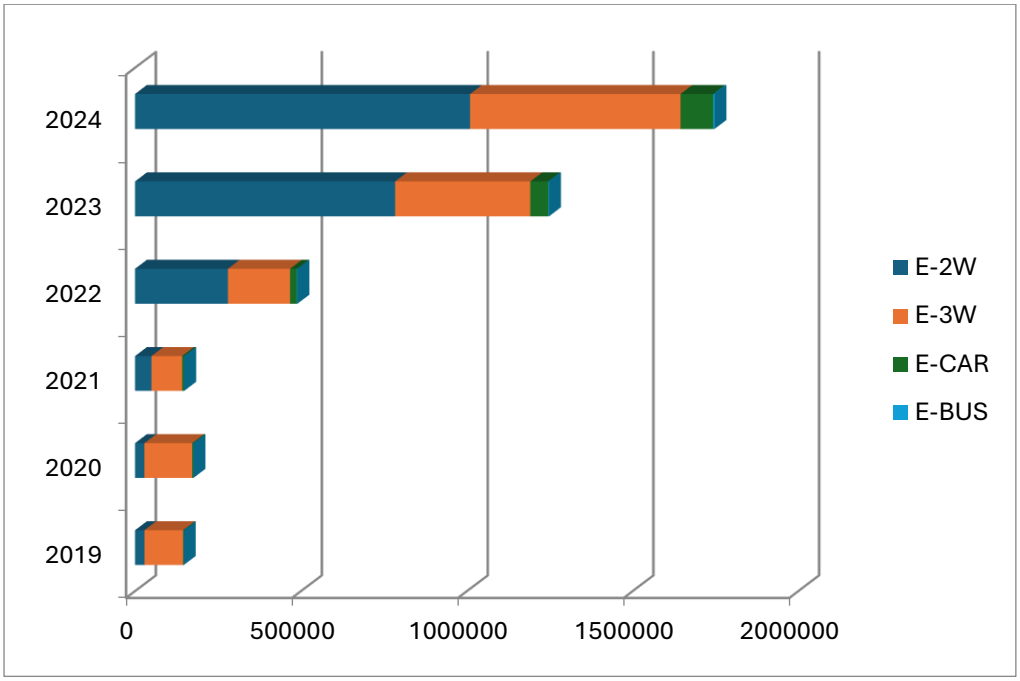
1.1.2. PRESENT GLOBAL STATUS OF ELECTRIC VEHICLE ADOPTION

The wide-scaled employment of electric vehicles started around the year 2007 in Europe, the US and China. Only electric cars were on the world's roads in 2010. In 2019, there were about 7.2 million electric passenger cars noted globally (Global outlook 2024). In 2023, electric car stock touched 40 million units. Among the existing electric vehicles, about 67% are BEVs while the rest are PHEVs. It may be noted that China accounted for more than 50% of the global stock of electric vehicles. In 2019, the market share of electric vehicles in Norway was 56% with the global average at 2.7%, as shown in Figure 2 (IEA global, 2019). Global EV car sales observed 3 million units in 2020, 10 million units in 2022 and 17 million units in 2024 (Global outlook 2024). The surge in electric vehicle sales is largely fueled by government financial incentives for purchasing EVs and the establishment of public charging stations. Additionally, there is a worldwide increase in investment in electric vehicles. As demand grows, original equipment manufacturers are enhancing their production capabilities and allocating specific facilities for EV manufacturing. This trend is propelled by government involvement and policies aimed at advancing the EV market and industry.

1.1.3. PRESENT STATUS OF ELECTRIC VEHICLES IN INDIA

Indian government undertaken many strategies on EVs. Still, progress on EV sales in Indian market is very slow. As per JMK Annual India EV report card 2024, in 2019, there were 1, 46,856 units electric vehicles including units electric three wheelers and electric two-wheelers (see Fig. 1.2). Electric cars and electric bus sales were only units and 147 units respectively. In 2024, total electric vehicle has reached units in which electric car and electric bus sale are only 99085 units and 3708 units respectively. Electric two-wheelers and three-wheelers segment are the most developed market for electric vehicles in India. The time-trend of electric vehicle sale in India is presented in Figure (JMK Annual India EV report card 2024).

Figure 1.2: EV sales in India.



Source: JMK EV REPORT 2024

In India e-car sale in FY 2024 was only 99,085 units whereas global e-car sales were about 17 million units. This figure is very low compared to global sales. The Automobile Mission Plan aims to position India as one of the top three global hubs for automobile manufacturing, achieving revenue to the tune of USD 300 billion by 2026.

Entry of electric vehicles (EVs) is bound to have certain unavoidable effects. Components like engine parts and drive transmissions are likely to suffer negative consequences, as the focus will shift from engine management to batteries and electric motors. Conversely, manufacturers of lighter automotive parts stand to gain, since EVs need to be lightweight to achieve the desired power efficiency.

As per the National Electric Mobile Mission Plan 2020, potential demand for EVs in India by 2020 is 5-7 million per year. A report published by the Norway-India Chamber of Commerce in 2018 mentioned that future demand of EVs in India by 2026 will be approx. 15 million per year (SIAM data). On the ground, only 1,76,126 units EVs were sold in FY 2020, which is very less figure against 2020 projection of 5-7 million units per year. As per the NITI Aayog report

2018, Zero Emission Vehicle, there will be plenty of job opportunities in the EV sector due to EV embracement in Indian market in subsectors like manufacturing, supply chain, battery production, sale, service, etc. Indian government has so far introduced a strategy that 30% of all vehicles on Indian roads will be electric by 2030. Many prominent writers have mentioned in news articles that upfront cost, range anxiety, Li-ion batteries, and inadequate charging infrastructure are the main challenges for EV adoption in India. Yatti Soni, Inc. 42 Staff, February 12, 2020; Shruti Mishra report, May 26, 2020, ET Auto.com and JuiliEklahare, EV manufacturing in India opportunities & challenges, and Publish Industry India are few examples. It can be concluded that the motor vehicle sector is facing a double sword problem of new business prospects in the EV sector and uncertainties of success considering the present challenges being faced by the EV sector.

From the preceding discussion, it is evident that electric vehicle embracement in India is relatively low in comparison to various grown economies because of several associated challenges in India. Along with these challenges, there are knowledge gaps among the policymakers and other stakeholders about the impact of deployment of electric vehicles on the economic factors like fuel and power requirement, emissions, and fuel import in India. The costs related to ownership of electric vehicles and quantum incentives to be provided for their promotion are also uncertain.

1.2. BUSINESS PROBLEM

Worldwide trend towards electricity driven vehicles is gaining momentum and European nations besides few more nations such as China and USA leading the charge through government incentives and robust infrastructure. By 2023, global electric car market had surged from 17,000 in 2010 to 40 million, driven by a rise in both demand and investments. However, India's EV market remains sluggish despite government policies aimed at boosting adoption. In 2019, EV sales in India were significantly lower than global figures, highlighting the gap between policy ambitions and market realities. The transition to EVs presents both opportunities and challenges for the Indian automobile industry. While the

shift will impact traditional sectors like engine parts and drive transmission, it offers growth prospects for lighter auto parts, renewable energy integration, and new supply chains. Experts suggest that India's reliance on imports for key EV components will gradually give way to a domestic supply chain, supported by the growth of green energy sources. Despite the government's goal of 30% EV adoption by 2030, drawbacks like high initial costs, limited run on a single charge, inadequate electrifying facilities, and dependency on lithium-ion batteries continue to hinder progress. The EV sector in India is at a crossroads, with potential for significant job creation and business opportunities, yet facing uncertainties that need to be addressed for its success.

Presently, the motor vehicle sector of India is facing a double sword problem of new business prospects, opportunities, and job creations in the EV sector and worried for the limitations of EV. Various types of electric vehicles in different segments will be introduced very soon. Drawbacks like high initial costs, limited run on a single charge, inadequate electrifying facilities, and dependency on lithium-ion batteries are the most significant challenges. This makes it unwilling for consumers to adopt the concept of EVs.

As per Maharashtra Pollution Control Board, in many major cities of Maharashtra such as Mumbai, Nagpur, Pune, Sangli, Solapur and Thane, air quality index is often found poor. As per iFOREST report on “Maharashtra GHG emission profile 2021-22”, Maharashtra contributes 10% of India’s total CO_2 emission. The motor vehicle sector in Maharashtra has a share of 12% carbon dioxide emission in the state (2021-2022). The state consumes approximately 90 MMT of petroleum per year. Maharashtra contributes 310 MMT (37.7 MMT from transport sector) GHG emission in 2021-22. As weather temperature crisis and air adulteration become increasingly urgent issues, environmental concerns plays central role in driving EVs embracement. People of Maharashtra have the knowledge of the environmental advantages of EVs. Studies show that users are trending to embrace eco-friendly technologies understanding environmental degradation as a significant issue (Reddy et al., 2023). Research has highlighted that the "green" appeal of EVs needs to be

coupled with clear communication about how EVs reduce emissions, noise pollution, and the overall carbon footprint (Aderibigbe et al., 2023).

1.2.1. BUSINESS PROBLEM STATEMENT

Maharashtra holds share of approximately 10% of India's cumulative automobile vehicle stock (Maharashtra hold 35.51 million out of 400 million automobile vehicle stock as on FY 2024). Similarly, Maharashtra has a share of approximately 11% of India's cumulative electric vehicle stock (Maharashtra hold 0.376 million out of 3.4 million electric vehicle stocks as on FY 2024). Maharashtra accounts for 10% of the country's GHG emission. The motor vehicle sector in Maharashtra has a share of 12% carbon dioxide emission in the state (2021-2022). In Maharashtra, the transport sector has a large contribution on carbon-dioxide emissions and fossil fuel consumption. Despite government incentives and growing knowledge of environmental problems, the embracement rate of electric vehicles remains low. This slow adoption impedes progress toward environmental goals, such as lowering air adulteration and reliance on non-renewable energy sources, both critical for sustainable development in Maharashtra. Businesses, policymakers, and society at large struggle to understand and address the barriers to EV adoption, such as high upfront costs, inadequate charging infrastructure, limited consumer awareness, and the uncertain effect of EVs on energy demands and on the environment. Without an increase in EV adoption, Maharashtra risks continuing heavy reliance on fossil fuels, missing out on potential reductions in emissions and air pollution, and failing to meet its sustainability targets. This issue highlights an urgent need to analyze factors influencing EV adoption and to evaluate its environmental, fuel consumption and economic impacts to inform business strategies and policy interventions.

1.3. DESCRIPTION OF THE STUDY AREA

The automobile sector in Maharashtra contributes 7% of the state's GDP. Maharashtra has 16602 enterprises of automobiles and automobile components including 26 Original Equipment Manufacturer (OEM). These industries are mostly located in Pune, Mumbai, Nagpur, Nashik, Aurangabad and Thane. The automobile sector in Maharashtra gives employment to approximately 3.4 lakh people. The state has got INR 11,111.4 crores (17.7% of total disbursal of entire

country) for FAME-II scheme since 2019. 45-84% of parts of IC vehicles will become obsolete and the small & micro enterprises comprising 97% of automobile sector will be affected due to automobile sector expected disrupt in the sector. Maharashtra has cumulative 35.51 million automobile vehicle registrations as on 31 March 2019 and annual 25.84 lakh automobile vehicle sale in the year 2019 (Motor Transport Statistics of Maharashtra 2018-19 report).

Maharashtra, one of India's most economically developed states, faces a growing need to address environmental concerns. The state is home to some of the most polluted cities in the country, with Mumbai and Pune often topping the charts for air pollution. As per Maharashtra Pollution Control Board, in many major cities of Maharashtra such as Mumbai, Nagpur, Pune, Sangli, Solapur and Thane, air quality index is often found poor. As per iFOREST report on "Maharashtra GHG emission profile 2021-22", Maharashtra contributes 10% of India's total CO_2 emission. The motor vehicle sector in Maharashtra has a share of 12% carbon dioxide emission in the state (2021-2022). The state consumes approximately 90 MMT of petroleum product per year. Maharashtra contributes 310 MMT (37.7 MMT from transport sector) GHG emission in 2021-22. As earth's climate system and atmosphere adulteration become increasingly urgent issues, environmental concerns act as a central role in driving the embracement of EVs. People of Maharashtra become aware of the ecological advantages of EVs. In response to adverse ecological impacts of fossil fuel-based transportation, the state government has recognized the importance of transitioning to cleaner alternatives, such as EVs.

1.4. PURPOSE OF THE WORK

Goal of this work is to pinpoint and quantify key elements of EV embracement intention of helping policymakers and industry stakeholders align strategies with consumer expectations. It aims to quantify how EV adoption reduces greenhouse gas emissions and assess its broader implications for the environment and public health. Further, assessing energy impact through reduced fossil fuel consumption the study provides key insights for energy transition strategies.

1.5. OVERVIEW OF METHODOLOGY

Following seminal works, we employed widely preferred methods for achieving set objectives. To explore the factors revealing EV adoption intention in Maharashtra, we extended theory of planned behavior to include environmental concerns, technological factors and state government's policy and support for EV adoption. Data was collected from 390 respondents using a well-structured and properly designed questionnaire. Data estimation methods included structural equation model and binary logistic regression model, besides diagnostic and validity models. Impact of EV adoption on carbon emission reduction and energy consumption in Maharashtra has been estimated with help of "Life Cycle Assessment" method. Additionally, Cost-benefit analysis of EV adoption using Life Cycle Cost model was employed in the study area.

1.6. RESULTS

Results revealed that environmental concerns, technology factors and government's policy and support positively and significantly affect the EV adoption intention in the state of Maharashtra. Further, socio-demographic factors like age, education, income, occupation and willingness to pay higher prices significantly affect the customer's willingness to adopt Electric Vehicle. Findings from the study uncovered that the operation cycle covers the maximum amount of CO_2 emission in every type of ICE and BEV vehicles i.e., motor cycle and scooter, auto rickshaw, motorcar and motorbus. BEV two-wheeler vehicle emits 34% less CO_2 than ICE two-wheeler in entire life cycle. BEV three-wheeler vehicle emits 72% less CO_2 than ICE three-wheeler in entire life cycle. Similarly, BEV cars emit 35% less CO_2 than ICE cars in their entire life cycle. Whereas BEV bus emits 7% more CO_2 than ICE bus in entire life cycle. All types of BEV and ICE vehicles have nearly 99.9% more CO_2 emission than all types of ICE vehicles. ICE motor cycle and scooter, auto rickshaw, motorcar and motorbus need petrol to the tune of 1560 litre, 5540 liter and 4033 liters. in its entire life. Similarly, ICE motor cycle and scooter, auto rickshaw, motorcar and motorbus need diesel to the tune of 1000 liter, 10500 litter, 8300 liter and 255 Kilo litre in its entire life. BEV motor cycle and scooter, auto rickshaw,

motorcar and motorbus need coal to the tune of 980 Kg, 2750 Kg, 5400 Kg and 214 tons in its entire life than ICE two-wheeler, three-wheeler, car and bus. BEV two-wheeler, three-wheeler, car and bus need relatively more natural gas than ICE two-wheeler, three-wheeler, car and bus.

1.7. SIGNIFICANCE OF THE STUDY

Due to environmental issues, increasing cost and diminishing stock of crude oil and technological superiorities, the world has started shifting towards electric drive train over IC engine driven vehicles. Govt of India has taken required initiatives in the form of MNRE incentive (2010), NEMMP 2020 (2012), FAME policy (2015), Second automotive mission (2015) and NITI ayog roadmap (2017) to promote EV growth.

Various incentives, subsidies, tax rebates have been declared by central as well as by various state govts. 14 Indian states have already formulated policies to promote EV sales. India has set deadlines of 2030 by which only electric cars will be sold in India. Despite the government's aggressive plans and policies, the on-ground EV sales have not picked up momentum. Only some good results have been seen in the two-wheeler and e-rickshaw segments. Although automotive OEMs are slowly taking steps towards EVs, the speed may not match government deadlines and present automotive market growth. As per The Economic Times, June 2019, India should postpone its EV plans for ten years due to battery issues and charging infrastructure issues. According to the findings, EVs and conventional vehicles are both part of the automotive sector. However, the implementation of the EV plan will have some impacts on the Indian automotive industry. With a critical evaluation of the research in the field of electric vehicles, it has been observed that there is very little research work conducted on the correlation between EVs and motor vehicle industry in India. Therefore, the study of impact of the EV plan on the Indian motor vehicle industry will be very useful. This work will also highlight the advantages and challenges of adopting EVs and the feasible methods, government policies, and supply chain issues regarding the Indian context. Thus, the current study will bridge the existing research gaps, except for the for the research gaps on charging cost, disposal, and recycling of Li-ion batteries, which will be

excluded from the present study due to time and resource constraints. This will highlight imperative issues to open avenues for future research.

1.8. THEORETICAL FOUNDATION OF THE STUDY

Understanding factors driving the adoption of electric vehicles (EVs) in India, namely in Maharashtra, and their subsequent effects on carbon emissions and the consumption of fossil fuels is the main goal of this study's conceptual framework. The study reveals important independent variables that influence consumers' intentions to use EVs, such as Attitude (AT), Environmental Concerns (EC), Perceived Behavioral Control (PBC), Policy Support (PS), Subjective Norms (SN), and Technological Factors (TF). Consumer attitudes on the economic and environmental advantages of EVs are reflected in attitudes, but environmental concerns highlight the need and understanding of lowering carbon emissions. While Policy Support emphasizes government programs like subsidies, tax breaks, and infrastructure development, Perceived Behavioral Control focuses on the accessibility, cost, and simplicity of EV adoption. Technological factors include improvements in car performance, battery economy, and charging infrastructure, while subjective norms reflect the impact of peer and society expectations.

All these factors work together to affect the main dependent variable, Adoption Intention (ADIN), which measures people's propensity to adopt EVs. Measurable effects, including lower carbon emissions and fossil fuel usage, follow from adoption intention. The relationship between external factors like regulations and technologies and the adoption decision is further enhanced or constrained by mediating variables, such as consumer awareness and faith in EV technology. By reducing costs, enhancing ease, and resolving performance issues, the framework suggests that technological and policy support factors have a beneficial impact on adoption intention. While Subjective Norms and Perceived behavioural control regulate association between external influences and adoption behavior, Environmental Concerns and Attitudes play a crucial role in inspiring consumers who are motivated by sustainability objectives.

A Life Cycle Assessment evaluates the environmental impacts associated with all stages of a vehicle's life, from raw material extraction to disposal or recycling. Comparative life cycle assessment concept has been used to achieve

impact on environment and fossil fuel consumption. Carbon emissions and fossil fuel consumption occurred in complete life cycle of IC engine vehicle and electric vehicle have been assessed separately and then total car bon emission and fossil fuel consumption by both type of vehicles are compared. Accordingly net carbon emission and fossil fuel consumption reduction due to adoption of electric vehicle is assessed.

Finally, the paradigm highlights the connection between personal choice and environmental sustainability by showing how EV adoption advances larger social objectives like less dependency on fossil fuels and lower carbon emissions.

1.9. STRUCTURE OF THE THESIS

The thesis is described in six chapters. Chapter-I discusses backdrop, statement of business problem, objectives, conceptual model, methodology, results, and significance of the study. Chapter II has been devoted to review of literature, theoretical and methodological issues, research questions, major findings and research gaps. Chapter III outlines case area and provides detailed account on environmental challenges of Maharashtra state. It also highlights the policy initiatives of the state government towards green energy and transportation sectors. Chapter IV delineates theoretical background of models, data collection and estimation methods. Chapter V deals with empirical results from estimated models or equations. Chapter VI documents summary and findings. It also lists suggestions, limitations and future areas of research.

Chapter 2

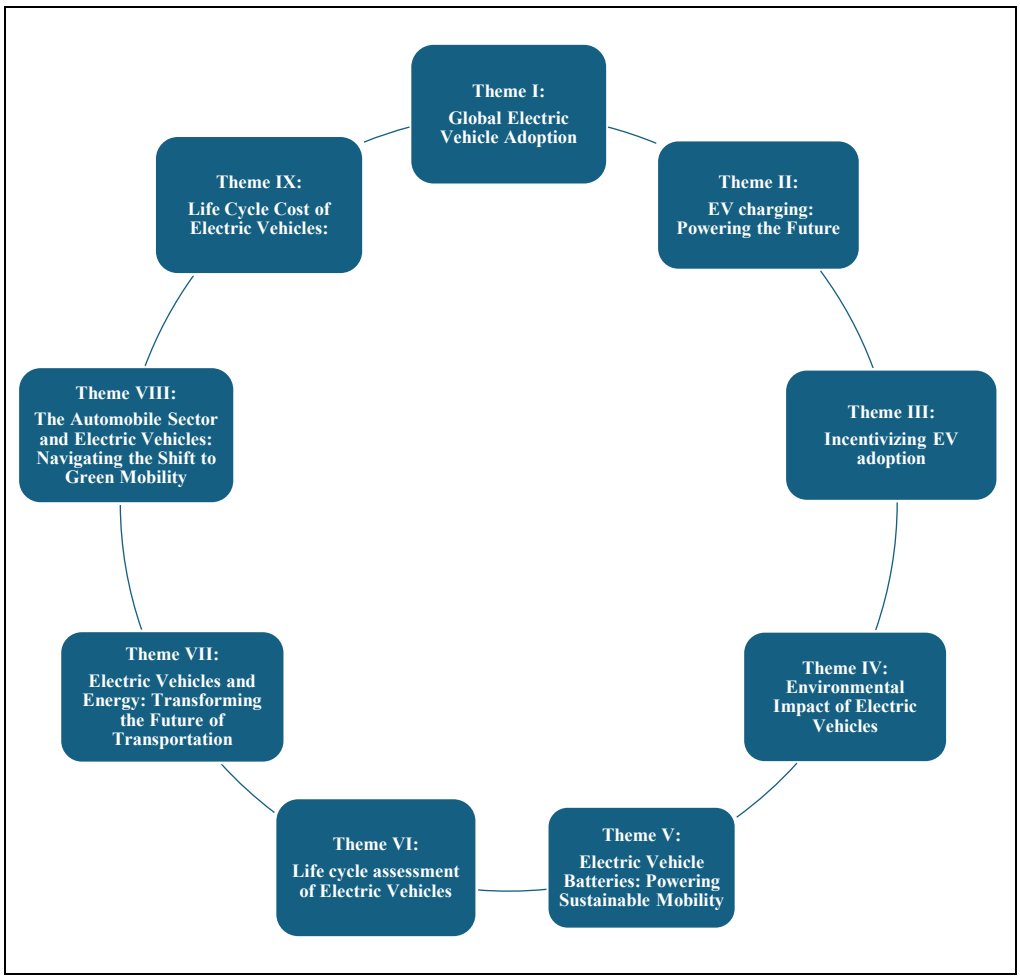
Review of Related Literature

CHAPTER 2
LITERATURE REVIEW

2.1. INTRODUCTION

The growing concern for climate change and the increasing acceptance of electric vehicles by the general population indicate there is a fair possibility that a wide electric vehicle industry will be observed soon. While it will take some years before electric vehicles fully gain control of the industry, electric two-wheeler and E-auto purchases in India rose substantially between 2016 and 2019, indicating that the transition is occurring now, although electric car sales rate is very slow. The transition to alternative power shifts many facets of the automobile business and underlines the need for more improvements as the kinds of cars that we use evolve. Therefore, this chapter's extensive review of studies on electric vehicle (EV) adoption examines various factors influencing changes from conventional vehicle to EVs. It assesses costs and benefits of adoption, incorporating perspectives on technology, economics, policy, and environmental impact. The aim of this chapter is to draw attention to the wealth and diversity of several recent studies that have been undertaken on the themes (see fig. 2.1) across countries in the last few years.

Figure 2.1: Literature Review in Themes



Keeping in mind the objectives of the present study, this review is confined to some important relevant studies and methods employed for electric vehicle adoption and assessing their benefits and costs. The principal aim of this exercise are:

1) Identify the research questions which these studies have attempted to answer.
2) Delineate the methodologies employed by these studies.
3) Enumerate the research gaps.
4) Against 1 through 3 above develop a rationale and justification for the present study.

Following theme wise extensive literature reviews have been carried out:

2.2. CHALLENGES AND OPPORTUNITIES IN THE INDIAN AUTOMOBILE INDUSTRY

A study was conducted by Munda, (2020) on the Indian automobile sector slowdown. The study observed that stable long-term policies and a stronger economic push from the government, along with technological upgrades, were necessary to revive the sector. Miglani (2019) noted in her research on the expansion of the Indian automobile sector that substantial investments in creating new indigenous technologies that are environmentally friendly and meet established high efficiency standards would enable India to ascend the value chain. Arya (2019) found in her analysis of the burgeoning automobile industry in India that the country possesses significant advantages in the evolving automotive environment, yet it must address major obstacles, such as a very limited supply of lithium and cobalt. A study was conducted by Tripathy (2018) on the future of the Indian auto industry and various choices and challenges. The paper attempted to understand and predict the adaptation of various technological upgrades, like BS VI implementation, electrification of drive trains, connected vehicles, smart factories, autonomous cars and business models etc., by Indian auto OEMs. The challenges the Indian auto industry faces, interposed against Indian regulations and market conditions, are also studied. The paper visualized the Indian auto industry's direction in the next five years until 2023. The study pointed out that life cycle emissions from EVs are not beneficial in all cases and should not be promoted when there is a heavy reliance on coal for power. This will shift pollution from urban mobile centers to centralized locations in the form of power plants. The research found that Indian automobile companies are unaware of emerging opportunities and are not taking advantage of them for a variety of reasons. For them, BS VI implementation by 2020 is the priority; the next priority is the electrification drive. The study is a little bit biased towards implementing electrification drives, fearing the challenges posed by EVs, which may temporarily affect the auto industry. Khaire and Singh (2017) conducted research on five sources of innovation within the Indian automobile market to examine the factors driving change in the industry and the inspirations that can be leveraged for innovation.

Their findings indicated that automotive OEMs and other stakeholders should harness these inspirations to craft strategies and direct their innovation efforts to thrive in the Indian automotive sector. Additionally, Jacob and Kattookaran (2017) carried out a study focusing on Indian motor vehicle industry expansion, particularly emphasizing two-wheeler segment.The study concluded that an increase in the income of general people and the liberation of industries from licensing were reasons for the growth of the sector. Kamal (2017) observed immense opportunities in the Indian automobile industry in his study. Yadav and Sahay (2016) conducted an investigation into the advancement of the Indian motor vehicle Industry and its effects on air adulteration. They employed a literature review and linear correlation technique for their study. Their findings revealed that the current turnover of sum of various types vehicles constitutes nearly 8% GDP of India and amounts to 38.3 billion US Doller. Contribution of rapid expansion of motor vehicle sector has enriched economy of India generating substantial employment opportunities. However, this growth has affected environment through air adulteration and world climatic changes. The study highlighted that the rise in the number of automobiles would lead to increased fossil fuel consumption, thereby escalating air pollution levels. The research noted that the data were based on current conditions, such as existing automotive and fuel technologies, but acknowledged the potential for technological advancements through green energy and alternative fuels in automobile industry to transform current operational methods. Gopalakrishnan (2014) noted in his examination of recent trends in the Indian automobile sector that both production and sales of automobiles were on the rise.

2.3. GLOBAL EV ADOPTION

The analytical research in this study (Sharma et al., 2020) indicated a favorable connection between purchaser acceptances and mood, subjective standards, and perceived conduct regulation. The study findings address the effects of the implementation of EVs in India and recommend potential studies based on the obtained results. Shankar and Kumari (2019) observed that awareness of the EV and the best services from sellers would help EV adoption. Khurana, Kumar, and Sidhpuria (2019) observed that attitude was the main influencing factor for

EV adoption. Dhar and Dixit (2019), in their study, observed that EVs are clean technologies. Niana, Haria, and Yuanb (2019) found that the suggested model reduces the barrier significantly to EV adoption and helps drive the adoption of EVs based entirely on the efforts of the private sector. Araújo, Boucher and Aphale (2019) observed that earning and average house price have positive effects on electric vehicle technology adoption. In the research study carried out by Mishra et al., (2019) aimed to investigate multiple buying power influencers of EVs in India by developing an economic and psychological paradigm focused on utility theory. The research showed environmental issues and efficiency as major factors affecting the actions of Indian customers in terms of EVs. Wang, Tang and Pan (2018) observed that charger's density, fuel price and road priority were significantly positive factors. Han, wang, Zhao and Li (2017) found that economics and operational parameters would greatly favor users perception and the EVs embracement goal. Ou et al., (2017) observed the government monetary incentives, low-cost micro electric vehicles were the China's PEV market. Liao et al., (2017) found that the monetary and scientific parameters greatly affected the usefulness of EV. Kieckhäfer et al., (2017) found that consumer's perception, battery life concern, inadequate charging infrastructure and government strategy were the negative factors of EV adoption. Faisal (2017) in his study observed that India could get sustainable solution from the analysis of developed countries electric vehicle adoption trends. It is observed in this study that the driving factors like technology & environment, public policy & economic and social & infrastructure would enhance the growth of EVs. Pathak and Shukla (2016) observed that electric vehicle market share would increase by 10% and carbon emissions would decrease by 5% by 2026 with replacing conventional power production to non-conventional power sources. Jabeen (2016) found that noise-free ride, reduced operational cost, decreased emissions and overall performance of EV were the enablers of EV adoption. The study concluded that driving range, charging infrastructure, charging cost, electrifying time were the barriers of EV adoption. Haddadian, et al., (2015) observed that technological barriers like battery technology, charging station, standardization, range and information gathering & data sharing, were the major challenges for EV adoption. Abotalebi,

Mohamed and Ferguson (2015) observed Stated preference has a positive effect on EV adoption. Mazur et al., (2013) found that regulations and consumer pressure were main drivers for change while economic indicators were not. Hidrue et al., (2011) found that range concern, electrifying time, battery cost and more initial price were major user worry for electric vehicles. Battery costs need to drop considerably.

Research has unveiled a myriad of variables impacting Electric Vehicle (EV) adoption. A study by Araújo et al. (2019) pinpointed income and median home value as crucial factors in early-staged EV adoption. Conversely, findings by Mishra and Malhotra (2019) suggest environmental concerns and efficiency are pivotal elements influencing Indian consumers' purchasing decisions regarding EVs. Utility theory underpinned a framework to investigate the multiplicity of buying power influencers of EVs in the Indian market. Research findings indicate that emergent technologies can be fostered by strong government policies as observed by Priessner et al. (2018). Additionally, charger density, fuel price, and road priority have been identified as significant factors contributing to the widespread adoption of EVs (Wang et al., (2018)). Research carried out by Han et al., (2017) revealed that monetary and performance values exert considerable influence on consumers' attitudes towards EV embracement. A study carried out by Ou et al., (2017) underscored the role of government monetary incentives in promoting low-cost micro electric vehicles within the Chinese PEV market. Liao et al. (2017) found that financial and technical attributes of EVs have a substantial impact on their utility. The papers by Kieckhäfer et al. (2017) and Faisal (2017) examined factors such as consumer perception, battery life concerns, lack of charging infrastructure, and specific personality characteristics that contribute to EV adoption. Their research also highlighted the potential for government policies to facilitate sustainable growth in the EV market. Changing the electricity generation mix to a renewable-based mix has been identified as a strategy to promote the adoption of Battery Electric Vehicles (BEVs) and reduce greenhouse gas emissions, as demonstrated by Pathak and Shukla (2016). The study further indicated that this shift can lead to a 10% increase in market share and a 5% reduction in GHG emissions by 2026.

The research also underscored the significance of environmental concerns, overall performance, and driving range in shaping consumers' perceptions and adoptions of EVs. The electrifying infrastructure inadequacy and electrifying costs are seen as primary barriers to EV embracement, while factors such as technological barriers, consumer knowledge, and demographics influence consumer intentions, as highlighted by the studies by Sang et al., (2015), Abotalebi et al., (2015), and Mazur et al., (2013). Overall, comprehensive understanding of the factors influencing EV adoption can aid policymakers in formulating effective strategies to promote the growth of EVs and foster a low-carbon economy.

2.4. ELECTRIC VEHICLE ADOPTION: INSIGHTS INTO CHARGING INFRASTRUCTURE, ENERGY INTEGRATION, AND TECHNOLOGICAL ADVANCEMENTS

Angeline and Rajkumar (2020) in their paper discussed in detail the problems raised by electric vehicles and their consequences for the transport and energy market. Decongesting the charging network may be introduced by building up charging stations in the public and private localities. They have observed that Vehicle-to-Grid technology would be the future growth of EV. Hove and Sandalow (2019) observed that EV industry with technological, operational and environmental parameters would transform transportation sector in coming days. Zhang et al., (2019) observed that the charging station can serve more EVs with the increase of energy storage capacity. Lin et al., (2019) indicated in his study that research and development in EV sector may improve parameters such as driving range, savings on charging system. Bak and Kim (2018) found that different types of charging system might be required for the similar type electric bus with different operational environment like electrifying time, travel distance and expenditure on fundamental facilities. Lee and Clark (2018) Observed that new rate designs, better smart metering and charging equipment technologies & charging infrastructure were to be developed and implemented for EV growth. Clairand et al., (2018) observed that the Smart charging methodology for EV optimizes the total costs. Gnann et al., (2018) found that the ratio of refueling stations and fast charging points per 1000 vehicles for EVs could be close to

normal motor car. Kong et al., (2018) Observed that there was a direct relationship between inadequacy of electrifying facility and degree of EV embracement. Helber et al., (2018) observed that time duration of linkage of EV to EVSE has a close relation with electrifying costs of EVs through solar power sources. Lacobucci et al., (2018) observed that the planned logic reduced three fourth energy cost over the unplanned electrifying cost in the case of SAEV + V2G. Fathabadi(2017) in his research observed that sufficient electric energy produced by the charging station during cloudless days to feed charging need and also catered for load grid requirement during non sunny days. Zhanga et al., (2017) stated that EV charging infrastructure facilities and charging system required to build a steady regular costing formula in China. Serradilla et al., (2017) found that present funding in EVSE rapid chargers was feasible of proving charging services on main expressways. Neaimeh et al., (2017) observed that present drawbacks of EVs such as range concerns to change it more attractive to future users could be overcome by using fast chargers. Daim et al., (2015) observed that EV owners and for the DSO would be benefitted with accurately linking of EVs in the disbursement network. Bockarjova et al., (2013) observed that time duration and costs involved with fast charging have negative effects on EV adoption. Environmental cost of CO_2 reductions was overvalued.

Electric vehicles have become an intense research subject in recent past because of its far-reaching consequences on the transportation and energy market. According to Angeline and Rajkumar (2020), expanding the charging network is essential to alleviate congestion, which can be achieved through the establishment of charging stations in both public and private areas. Furthermore, the adoption of Vehicle-to-Grid technology is expected to be a pivotal factor in the future growth of electric vehicles. Studies have shown that the electrification of vehicles, coupled with transportability and vehicle reliance, will lead to transformative changes in conveyance sector (Hove and Sandalow, 2019). The charging cost of electric vehicle is heavily affected by causes like seasonal variation and specific connection time (Pasetti et al., 2019; Helber et al., 2018). Higher monetary savings and reduced requirement for extra hardware because of Vehicle-to-Building

scheme can be achieved with enhanced battery capacity (Englberger et al., 2019). Research has also highlighted the importance of increasing energy storage capacity in charging stations to achieve growing fleet of electric vehicles (Zhang et al., 2019). Additionally, studies emphasize the need for increased research and development to expand the driving range of electric buses, thereby maximizing cost savings in e-bus charging systems (Lin et al., 2019). Research by Neaimeh et al., (2017) revealed that the functionality of fast chargers may alleviate range-related apprehensions, thereby enhancing the appeal of battery electric vehicles among prospective users. Studies by Sheppard et al., (2016) discovered that the installation of low cost EV electrifying station facilities tends to focus on densely populated areas within cities. Jing et al., (2016) found that electric vehicles' inherent characteristics, such as range limitations, significantly influence their routing behavior and the design of associated charging infrastructure networks. Conversely, Daim et al., (2015) demonstrated that the effective integration of electric vehicles within distribution networks presents benefits for both owners and distribution system operators. Meanwhile, Bockarjova et al., (2013) identified money and time duration involved with fast charging a significant obstacle to electric vehicle embracement, alongwith environmental savings valued at €160 per ton of CO_2 reduction being substantially above market rates.

2.5. INCENTIVES AND POLICY MEASURES DRIVING EV ADOPTION

Heymanna et al. (2019) have shown in their studies that minimum technological embracement imbalance with particular motivated design could decrease global network expansion costs. Li et al. (2018) stated that only one government department should frame EV policies to address the difficulties of disunited power in lawmaking and realisation. EVs can be promoted with powerful and firm federal goals, monetary incentives and local benefits. Wang et al. (2018) observed that the optimization model would be helpful for policymakers to materialize maximum number of EVs within specific fund. Jenna et al. (2018) indicated that degree of EV embracement could be enhance with financial subsidies and incentives like specific road access, and enhanced user information. Chen et al., (2018) suggested that EV embracement in China has

grown and maintained due to powerful incentive policy. Egnér et al. (2018) observed that usefulness of BEV could be enhanced with developed public charging infrastructure undermining the drawbacks like range concerns and inadequate private charging facilities. Rokadiya (2016) sheds light on the Indian scenario regarding incentives provided under the FAME scheme, central infrastructure cess, state value-added tax (VAT), and additional state subsidies for different types of EVs. Aasness &Odeck (2015) observed that the wide range of economic incentives provided by the Norwegian government have made EVs much cheaper to purchase and use.

A plethora of research suggests that the diminution of global network expansion costs and the mitigation of technological disparities can be achieved by integrating tailored incentive initiatives. The strategic allocation of authoritative responsibility among ministries, as proposed by Li et al. (2018), is conducive to efficacious implementation of electromobility strategies. The enhancement of national targets, complemented by purchasing incentives and locale-specific secondary benefits, has been identified as a pivotal factor in the promotion of electric vehicles. Notably, optimization models can serve as a valuable tool for policy-makers seeking to maximize the adoption of battery-electric vehicles within constrained budgets (Wang et al., 2018). Additionally, the augmentation of monetary incentives, the provision of preferential access to high-occupancy vehicle lanes, and the elevation of consumer awareness can significantly augment the effectiveness of EV adoption (Jenna et al., 2018). Furthermore, the maintenance of a robust subsidy regime continues to provide substantial support for the EV growth in China, as observed by Chen et al. (2018). The development of public charging infrastructure, as proposed by Egnér et al. (2018), can mitigate concerns related to range anxiety and limited charging options that could increase the usefulness of BEV. Hence, the convergence of these factors is likely to contribute to the accelerated adoption of electric vehicles.

2.6. ENVIRONMENTAL IMPACTS AND EMISSIONS REDUCTION POTENTIAL OF ELECTRIC VEHICLES

Xiong and Ma (2019) found that BEVs were less emission-intensive than PHEVs in present power mix in China. Vidhi et al., (2018) observed that EV adoption

would reduce overall emissions, including NOx, SO2SO2, CO, and CO_2, with a better power mix. Tripathy et al., (2018) observed that the life cycle emissions of EVs were not beneficial in all cases and should not be promoted when there was a heavy reliance on coal for power. Research conducted by Yadav (2017) revealed that there was a strong relationship among automobile sale and resultant CO_2 emissions. Abhyankar et al., (2017) observed that EV adoption would reduce emissions, crude oil imports, and energy costs. Tatari (2017) observed that the life-cycle fuel costs of trucks could be improved by over 70% using a proper grid mix. Schmid (2017) observed that the more energy produced through renewable resources, the greener electric cars would be, resulting in zero emissions, closer to the truth. McLaren et al., (2016) found that BEVs using workplace charging on a low-carbon grid would provide the greatest emissions reductions. Results from Li et al.'s (2016) study indicated that FCEVs powered by natural gas has more power efficiency and carbon emissions than BEVs. Research carried out by Jiang et al., (2015) found that solar-powered charging stations model for EVs was acceptable from an economic point of view. Moreover, this model displayed a high pollutant emission reduction potential. Majumdar et al., (2014) observed that the BEV had the benefits of reduced environmental pollution, crude oil imports, and use of conventional power and increased use of renewable energy, and financial benefits through carbon trading. Research by Mierlo et al. (2014) indicates that electric vehicles exhibit greater environmental sustainability throughout their lifecycle. Hawkins et al., (2013) concluded that EV powered by non conventional energy sources holds considerable potential for mitigating the environmental repercussions of transportation, specifically concerning climate change, air quality degradation, and fossil fuel depletion. Alternatively, Hadley (2009) noted that electric vehicles with coal and fossil fuel-based power generation result in higher emissions, but those utilising clean power generation systems exhibit significantly reduced emissions. Furthermore, Ahn et al. (2008) discovered that alternative fuel vehicles available on the market contribute to decreased demand for gasoline and diesel fuels and a corresponding reduction in pollutant emissions.

2.7. ADVANCEMENTS IN BATTERY TECHNOLOGY AND INFRASTRUCTURE FOR ELECTRIC VEHICLE

Ali et al., (2019) in their study discovered that Li-ion batteries possess several characteristics rendering them highly suitable for electric vehicles, specifically in regards to extended lifespan, high energy density, nominal voltage, and relatively inexpensive cost. Varga et al., (2019) found that driver range anxiety could be reduced with the incorporation of technical characteristics of the EV, visual instruments, and interactive maps. Studies conducted by Pan et al., (2019) have demonstrated that an optimised direct prosecution (DP) approach outperforms a rule-based strategy in terms of system efficiency and energy consumption. Gaines and Nelson (2019) stated that electric drive vehicles with an aggressive program could be supported for decades with known supplies of materials for lithium-ion batteries. Liaoa, Molina, Timmermans, and Wee (2019) observed that vehicle leasing was the most preferred option and battery leasing was the least preferred for BEV. Research carried out by Kavanagh et al., (2018) indicates that the booming EV market is stipulating increased demand for lithium resources, thereby generating concerns regarding potential supply shortages. Melliger et al., (2018) stated that charging infrastructure was the answer to the range limitation of EVs. Lia et al., (2018) observed that advanced BMS could well improve battery operation efficiency and extend service life. Kumar et al., (2018) stated that battery technology would be a key factor in the growth of e-vehicles in India. There is a need for the government to incentivize and subsidize EVs.

2.8. LIFE CYCLE ASSESSMENT OF ELECTRIC VEHICLE AND HYBRID ELECTRIC VEHICLE

A study conducted by Grijalva and Martínez in 2019 revealed a substantial decrease in CO_2 emissions, with estimates suggesting a potential reduction of 92.6% following the replacement of conventional bus fleets with electric vehicles, as compared to 2018 emission levels. Gupta et al., (2017) observed that hybridization had higher potential for Indian driving conditions in reducing tank-to-wheel energy use and GHG emissions. A study by Wolfram (2016) demonstrated that the varying costs of power trains were predominantly

influenced by battery and fuel cell expenditures. Forecast data indicated a substantial decline in power train costs between 2015 and 2030. Evaluations of the carbon footprint associated with battery electric vehicles, utilising European grid-mix electricity, revealed a notable reduction in emissions, yielding a value of approximately half the average emissions from European vehicles. The study conducted by Egedea et al., (2015) found that environmental impacts of EV depends on factors like resource extraction, production, use, recycling, water, emissions, noise, waste heat, etc. Studies carried out by Ghosh(2014) suggested that Battery Electric Vehicles (BEVs) exhibit reduced lifetime costs and carbon emissions. Notwithstanding these advantages, PHEVs would still offer contrasting environmental and economic benefits compared to conventional vehicles. Nordelof et al. (2014) in their research indicated that Electric Vehicles (EVs) may actualize their full potential in curbing global warming provided that global electricity production is transitioned to a cleaner, virtually fossil-carbon-free energy source. Additionally, Lebeau et al. (2013) in their studies indicated that Electric Vehicles within the existing premium automobile segment are economically viable. Hsu (2013) observed that the issue of the sustainability of EVs (and PHEVs) would depend on electric power generation by utilities. Aguirre et al., (2012) observed that BEV was more energy efficient and less polluting than a CV when the electricity mix had sufficient renewables. 33% of renewables were the most energy efficient and the least polluting. Lowell, Jones, and Seamonds noted that the net present value of yearly societal benefits was anticipated to be at least $261 million annually by 2050. According to Constantinesamra et al., (2008), plug-in hybrids could significantly cut greenhouse gas emissions and reduce reliance on oil when paired with a low-carbon electricity system. Delucchi et al., (2001) identified in their study that high battery cost was the primary factor behind the increased initial expenses and the rise in insurance and registration costs for electric vehicles.

2.9. LIFE CYCLE ASSESSMENT OF BATTERY ELECTRIC VEHICLE

Qiang et al. (2016) found that important parameters for battery material extraction and battery Production processes include total energy consumption,

carbon dioxide emissions, nitrogen oxides, sulfur oxides, and particulate materials for the same energy capacity batteries. Zackrisson et al. (2021) found in their study that life cycle assessment could be applied for estimating and enhancing environmental viability of EV traction batteries. The significance and utility of the LCA method for the growth of various viability parameters of the traction batteries of electric vehicle has been elaborated by the author. The study also indicated that very less data are available for various EV battery structure and that there are certain systematic difficulties with LCA.

Temporelli et al. (2020) in their study highlighted and analyzed and explained related data for LCA of conventional motor vehicle battery EV battery. Complete life cycle phases like raw material extraction, material manufacturing, battery production, material handling and transportation, utilization and end of life together with recover, recycle and reclaim have been discussed in the study. Aichberger et al., (2020) in their study described complete sequence of different LCA phases of EV battery including battery management and battery cooling system.

In the research carried out by Wang et al., (2020) found that manufacturers would not mention accurate price of battery considering warranty repair and replacement. Dai et al., (2019) analyzed and described in their study about cradle to gate analysis of nickel manganese cobalt oxide battery covering carbon emission, energy consumption and other environmental effects during manufacturing and use. Ellingsen et al., (2014) described in their research on EV battery that battery cell production, negative and positive electrode paste emitted maximum environmental effect and green energy could effect to a great amount. Aichberger et al., (2020) concluded in their research that carbon emission and energy consumption could be reduced significantly through recycling process and second life utilization. Tolomeo et al., (2020) mentioned in their study that very less number of nations produced Li-ion battery in the world and China had the maximum amount of share (41.8%) of Li-ion battery production.

2.10. LCA OF FUEL CYCLE

In the study conducted by Liu et al., (2020) observed that carbon emission was maximum during crude extraction stage for petroleum fuels. Requirement of energy and other inputs were highest in case of diesel production in comparison with gasoline and LPG. The study also discussed about "Well to Tank" and "Tank to Wheel" aspects of fuel life cycle. Forman et al., 2015 have used "Greenhouse gases regulated emissions and energy use in transportation (GREET)" model for fuel life cycle for petroleum products. Life cycle carbon emission and energy flow for various fuels such as gasoline, diesel LPG and jet fuels have been discussed in the study.

2.11. LIFE CYCLE ASSESSMENT OF POWER CYCLE

Unnikrishnan et al., (2018) in their research on Indian coal thermal power plant, mentioned about various environmental effects which were estimated through LCA method. Primary data on emissions and other pollution effects on the environment were used in the research. The authors concluded that huge amount of coal mining for thermal power plant were responsible for carbon emission and climate shift. Hertwich et al., (2015) indicated in their study that environmental effects of various types of power production like coal, solar, wind, and hydropower was analyzed and critically discussed. Masanet et al., (2013) highlighted the utility of LCA in power generation intricacies, various adulteration effects on air, water, and soil to power production stages and betterment scope green power generation in the current scenario. Kim et al., (2021) described a life cycle power production from traditional sources such as black coal, lignite, natural gas, nuclear, and non-conventional sources such as wind, solar, and hydro and estimated environmental effects and end of life effects in the Czech Republic.

2.12. LIFE CYCLE EMISSION FROM FUEL

The fuel life cycle, colloquially referred to as "Well-to-Wheel" cycle, encompasses a series of interconnected phases, namely feedstock production and acquisition, logistical transportation, conversion into energy products, supply chain dissemination, and ultimately, power generation through

combustion processes. This section includes different research that focused on calculating emissions at various stages of the fuel life cycle. Carbon emissions are quantified through an equilibrium-based approach applied in the GREET model, where CO_2 emissions are expressed in grams per unit of energy released from fuel combustion.

2.13. LCA OF CONVENTIONAL VEHICLE

Conventional vehicles powered by diesel and gasoline are the most commonly used in the transportation sector and are the primary contributors to CO_2 emissions (Puig et al., 2021). In terms of greenhouse gas emissions and air quality, electric vehicles (EVs) might offer a more favorable alternative. EVs provide numerous advantages, such as superior tank-to-wheel fuel efficiency, minimal or no local air pollution, and quiet operation. While Shi et al. (2016) concentrated on the consumption phase when comparing traditional and electric cars, the manufacturing process is also significant in this comparison. We create and share a transparent life cycle inventory for both conventional and electric vehicles, allowing us to evaluate them across various impact categories. The research has examined the life cycle assessment (LCA) of conventional vehicles, encompassing their production, full operation and maintenance, salvage, recycling, and reuse, as well as their fuel cycle (Mayyas et al., 2017). The study connected energy use, greenhouse gas emissions, and costs at each stage.

2.14. ENERGY, OIL DEPENDENCY, AND EV ADOPTION CHALLENGES

Padmanathan et al., (2019) concluded in their study that solar energy had not yet reached the anticipated level for all types of segments due to high capital costs. Kah (2018) stated that crude oil demand would not decline with declining conventional vehicles due to oil demand in other sectors. Chakraborty (2016) found in their study that the import dependence of crude oil in India was approximately 75% of oil consumption. Egede, Dettmer, Herrmann, and Kara (2015) observed that an energy mix and a proper distribution system with energy storage were the answers to EV adoption. Cauwer et al., (2015) have

indicated in their study that the necessity of contextualizing the energy consumption of electric vehicles within the boundaries of the energy supply chain. Saxena et al., (2014) observed that the transport sector depended on imported oil. Jiang et al., (2014) observed that a maximum load increase was observed at each load bus on the system.

2.15. COST ANALYSIS ON LIFE CYCLE BASIS OF ELECTRIC VEHICLE AND CONVENTIONAL VEHICLE

The life cycle cost analysis is overall estimation of all cost associated with any vehicle accounting from raw material extraction to end of life. Furch et al. (2022) considered vehicle procurement cost, vehicle repair cost, vehicle running cost and disposal cost for life cycle cost model for any vehicle. Karkare, (2020) factored total cost of IC engine and electric vehicles as vehicle purchase cost, overhead cost such as government taxes, registration charges etc., insurance cost, maintenance cost, battery replacement cost, cost of fuel for IC engine vehicle, cost of electricity for electric vehicle charging and government incentives etc. Hu et al. (2020) considered Social Cost of Carbon (SCC) as monetary value of environmental damage and human health damage caused by the emitted carbon dioxide while calculating life cycle cost of a vehicle. Rajagopal et al. (2024) taken account of capital cost, fuel cost, maintenance cost, and operations cost while considering total cost of a vehicle. Kirsanovs et al. (2020) included car purchase costs, costs related to mileage, maintenance, servicing costs, Car utilization costs such as CO_2 emissions tax etc. in total cost of a vehicle. Dash et al. (2021) considered battery replacement cost, tax, fueling cost, insurance cost, maintenance cost, purchase cost of vehicle, and depreciation cost for calculating total cost of a two-wheeler vehicle. The LCC model introduced by Raustad (2017) includes the vehicle costs of purchase price with federal incentives, salvage value, fuel consumption (electricity and liquid fuel), insurance, maintenance, and state tax. Sheth et al., (2019) described total cost of ownership as summation of the cost of bus procurement, the cost of diesel, the cost of operation and maintenance, cost of bus replacements, the cost of electricity, and environment damage cost. Green et al. (2019) considered total cost of ownership as sum of purchase cost, purchase tax, subsidy, operating cost, fuel cost, insurance cost, maintenance cost,

battery replacement cost etc. Wong et al. (2010) counted purchase price, freight, insurance and all other charges incidental to the sale and delivery of the car to Singapore, Excise Duty, Goods and Service Tax, Certificate of Entitlement Fee, Registration and Additional Registration Fees, Green Vehicle Rebate Scheme, pollution cost. Vijaykumar et al. (2021) considered capital cost, vehicle utilization cost, fuel cost, maintenance cost and staff cost as cost elements of total cost of ownership of a vehicle. Malmgren, (2016) has mentioned using the Social Cost of Carbon (SCC) to estimate climate benefits of CO_2 emissions reduction. Sankaran et al. (2022) stressed upon to assess the economic efficiency of EV over ICE in terms of total cost of ownership i.e. the total sum of the cost incurred due to purchasing, owning, operating & maintaining the vehicle over its life. This study carried out by Chakrabarti et al. (2020) compares the operational costs of electric vehicles and internal combustion engine vehicles, showing that EVs have significantly lower per-km running costs due to the lower price of electricity compared to petrol and diesel. The study also highlights how government subsidies and incentives can further reduce the cost of EV ownership in India.

2.16. RESEARCH PROBLEM

As per the Global EV Outlook 2020, 7.2 million EV car stocks are present worldwide. Out of this 7.2 million, China counts for 3.4 million EV cars, Europe counts for 1.75 million EV cars, and the USA counts for 1.45 million EV cars. The China Association of Automobile Manufacturers, or CAAM, reported in 2020 that annual EV sales in China were more than 1.3 million. As per the "Society of Manufacturers of Electric Vehicles", in India total EV cars sold up to 2019 were only 7200 units. In India, two-wheeler and three-wheeler EV sales figures for FY 2017-18 and 2018-19 are 54000, 126000, and 520000, respectively (AutocarIndia.com report).

Therefore, it can be concluded that the present state of EV adoption in India is far below the target. Relative to EV developed nations like USA, China, and various European countries, India lags significantly in terms of electric vehicle adoption. Though the sale rate of two-wheeler and three-wheeler electric vehicles has been found to be on an upward curve, the state of sale of four-wheeler electric vehicles is very low. Though Indian government has taken

corrective actions to address the issues, satisfactory results have yet to be seen (NEMMP 20, FAME India). Everyone concerned with e-mobility is interested in knowing the reasons for the slow rate of EV adoption and how the growth rate of EV adoption in India can be enhanced.

This research investigation endeavours to examine the preferences and attitudes regarding the adoption of electric vehicles in India, with a particular emphasis on understanding the determinants that drive this phenomenon. Central to this inquiry is the evaluation of the efficacy of electric vehicles in mitigating emissions from the transportation sector and concurrently reducing reliance on fossil fuels, particularly within the Indian context. The study additionally seeks to scrutinise the degree to which a decrease in emissions and fossil fuel consumption is being realised through the adoption of electric vehicles in India. As it was observed in the literature review, adoption of EV depends upon various attributes like environmental concern, economic factor, perceived usefulness of technologies, subjective norms, socio-demographic etc. It is very much necessary to know which attributes Indian customers prefer most for the adoption of EVs and which attributes act negatively or negligibly. An extensive analysis considering parameters that promote EV embracement in India is essential for its accelerated growth, thereby promoting the development of the Indian automotive sector. Consequently, this would contribute to mitigating environmental issues, such as diminished air adulteration and reduced dependence on conventional fuels, in pursuit of a sustainable transportation paradigm.

Insufficient empirical research exists to elucidate the pivotal factors influencing electric vehicle adoption in Maharashtra, India, alongside its attendant environmental and economic ramifications. Priorities placed on electric vehicles through policy do not concomitantly facilitate comprehensive knowledge regarding the determinants and catalysts of consumer and commercial EV uptake.

2.17. RESEARCH GAPS

The major research gaps found from the literature review are summarized below (also refer in table 2.1):

Promotion and Acceptance of Electricity Driven Vehicles in Indian Context

- Factors for EV Promotion: The need for research on specific considerations that encourage electric vehicle (EV) acceptance in the Indian context, including pricing, advertising, and product design.
- Purchase Intention: Understanding consumer purchase intention towards EVs, emphasizing primary data collection over secondary data.
- Impact of Incentives and Awareness Campaigns: Evaluating the effectiveness of incentive and subsidy policies, and the role of awareness campaigns and consumer information systems in promoting EV adoption in India.
- *Infrastructure and Economic Implications of EV Adoption*
- Charging Infrastructure: Investigating the effect of EV recharge infrastructure on embrace rates and analyzing recharge costs specific to the Indian context.
- Renewable Energy Integration: Exploring the need for a renewable energy mix to enhance emissions reductions and economic efficiency in EV adoption.
- Electrification of Public and Heavy Transport: Research on the potential of electrically driven buses and trucks as part of the broader strategy to capture the EV opportunity.

Environmental and Lifecycle Impacts of EVs

- Environmental Impact of EVs: Assessing the environmental effects of EV adoption using primary data, including emissions per kilometer, crude oil savings, and the current grid power mix in India.
- Battery Lifecycle and Recycling: Analyzing the environmental effects linked with the manufacture, utilization, and end use of EV batteries, with a focus on recycling and sustainability.

Table 2.1: Shows the research gaps, research questions, and research objectives

Research Gap	Research Question	Research Objectives
RG1- Insufficient exploration of consumer preferences and attitudes towards EV adoption across India's diverse socio-economic landscape.	RQ-1 How environmental concerns, technological developments and policy measures influence EVs adoption intention in Maharashtra?	RO-1 To analyze factors influencing the adoption intention of electric vehicles in Maharashtra.
RG2- Limited empirical data on the real-world impact of EV adoption on emissions reduction in India, with a lack of longitudinal studies.	RQ-2 What are the benefits in terms of emission reduction that will impact Indian automotive sector due to EV adoption?	RO-2 To assess the impact of EV adoption in terms of carbon emission reduction in Maharashtra.
RG3- Scarcity of comprehensive assessments of EV adoption's impact on fossil fuel consumption in India, including full lifecycle and supply chain considerations.	RQ-3 What are the effects in terms of fossil fuel consumption that will impact Indian automotive sector due to EV adoption?	RO-3 To evaluate the impact of EV adoption on fossil fuel consumption in Maharashtra.

Several studies have been conducted on electric vehicle adoption, incentives, environment issues, heavy dependency on the import of fossil fuels and its insufficiency, EV charging infrastructures, EVs and RE, the high cost of lithium-ion batteries, the complexities of battery management systems, the state of the automobile sector, etc. The policies of major players in the field, like the USA, China, and European countries, were also studied. However, very few studies have been dedicated exploring the “preferences and attitudes” of individuals towards embracement of EVs in the context of a developing nation such as India. A significant research gap exists in examining the repercussions of electric vehicle (EV) integration within the Indian automotive industry, as well as the variables influencing the expansion of EV adoption in the Indian

automotive sector. But life-cycle emissions are totally dependent on the nature of electricity generation. The life-cycle emission of EVs will be higher than conventional vehicles if they use electricity produced from fossil fuels like coal or oil. Not much research on this aspect has been found in the Indian context.

Chapter 3

Study Area: Maharashtra the Automobile Hub of India

CHAPTER 3
STUDY AREA: MAHARASHTRA THE AUTOMOBILE HUB OF INDIA

3.1. INTRODUCTION

Maharashtra has 9.4% India's total population. In terms of geographical area, Maharashtra holds 10% of India's total area. The four biggest cities i.e. Mumbai, Pune, Nagpur and Nashik of the country are in Maharashtra. This is an investor friendly state. 15% of the country's total GDP comes from Maharashtra. Per capita GDP (Rs 38,785) is higher than national per capita GDP (Rs 30,097). It is the Industrial state in the country. It is also the automobile hub of the country due to factors like availability of strong human capital, well established financial institution, geographical advances with seaport, road network, automobiles and automobile component manufacturing hub, technical institution, presence of industrial houses, good investment record, several battery manufacturing units and R&D facility etc.

The automotive cluster in Maharashtra has a history that is long and deep and goes back to the 1940s. Maharashtra housed some of India's earliest homegrown automakers like Tata Motors, Bajaj Motors, and Force Motors in its formative years. While Mahindra & Mahindra started in Punjab, it later settled in Maharashtra and enhanced the manufacturing ecosystem of the state. The 1980's was an important decade for the cluster. Linkages to Japanese car makers began to foster after the Indian government policies of deregulation and de-licensing. A prominent example of this was the formation of Swaraj Mazda in 1983 which led to the proliferation of ancillary industries in the region. The period between the 1990's and 2000's marked the growth and expansion of the cluster. A range of popular vehicles was launched by Tata Motors causing several supporting industries to move to the state. In addition, established foreign automobile manufacturers located their assembly plant in Maharashtra, which aided the technological progress and development of local supply chains.

As per Ecosystem report May 2024, Maharashtra produces 20% of vehicle manufactured in India. The automobile sector in Maharashtra contributes 7% of the state's GDP. Maharashtra has 16602 enterprises of automobiles and automobile components including 26 Original Equipment Manufacturer (OEM). These industries are mostly located in Pune, Mumbai, Nagpur, Nashik, Aurangabad and Thane. The automobile sector in Maharashtra gives employment to approximately 3.4 lakh people. The state has got INR 11,111.4 crores (17.7% of total disbursal of entire country) for FAME-II scheme since 2019. 45-84% of parts of IC vehicles will become obsolete and the small & micro enterprises comprising 97% of automobile sector will be affected due to automobile sector expected disrupt in the sector.

Maharashtra has cumulative 35.51 million automobile vehicle registrations as on 31 March 2019 and annual 25.84 lakh automobile vehicle sale in the year 2019 (Motor Transport Statistics of Maharashtra 2018-19 report).

3.2. TREND OF CO_2 EMISSIONS (IN MMT)

The data in table 3.1 represents CO_2 emissions in million metric tons (MMT) from the years 2015 to 2022. From 31.6 MMT in 2015 to 40.8 MMT in 2019, there was an upward trend in CO_2emissions, with the largest rise taking place between 2018 and 2019.There is a notable increase, reaching 41.9 MMT, which may be due to various world conditions (e.g., post-pandemic rebound) or variables like increasing industrial activity. After 2020, there was little variation in emissions, which decreased to 35.6 MMT in 2021 and increased somewhat to 37.7 MMT in 2022.

According to the data, emissions generally increased between 2015 and 2020, then slightly decreased and then slightly increased in the years that followed. This might point to shifting patterns in energy, transportation, and industrial emissions throughout time.

Table 3.1: Maharashtra Road Transport Emission Annually (2015-22)

Year	CO_2 Emission in MMT
2015	31.6
2016	34.4
2017	35.8
2018	38.4
2019	40.8
2020	41.9
2021	35.6
2022	37.7

Source: *Maharashtra GHG Emission Profile (iFOREST)*

From 15.77 million in 2010 to 19.43 million in 2012, the number of vehicles rose gradually, indicating a modest increase in the initial years (see Table 3.2). Due to rising demand and economic expansion, the number of automobiles climbed at an average yearly pace of almost 2 million, reaching 25.59 million by 2015. From 2016 to 2019, the growth rate remained constant or even increased, reaching a peak of 35.51 million in 2019. With an average yearly rise of more than 3 million vehicles, the increase throughout this time span demonstrates a persistent demand for automobiles. The number of vehicles has neither decreased or stagnated, indicating a robust and ongoing market expansion. This tendency may be explained by urbanisation, economic expansion, income increases, and the availability of more reasonably priced automobiles. The demand for fuel and infrastructure development, pollution, and traffic congestion may all be impacted by this spike in vehicle numbers.

Table 3.2: Total Number of Vehicles Maharashtra 2018-19

Year	Number of Vehicles in Millions
2010	15.77
2011	17.43
2012	19.43
2013	21.49
2014	23.39
2015	25.59
2016	27.87
2017	30.22
2018	32.95
2019	35.51

Source: Motor transport statistics of Maharashtra 2018-19

3.3. MAHARASHTRA AND EV ADOPTION

Maharashtra, one of India's most economically developed states, faces a growing need to address environmental concerns. The state harbours numerous urban centres amongst the most polluted in the nation, with Mumbai and Pune often topping the charts for air pollution. As per Maharashtra Pollution Control Board, in many major cities of Maharashtra such as Mumbai, Nagpur, Pune, Sangli, Solapur and Thane, air quality index is often found poor. As per iFOREST report on "Maharashtra GHG emission profile 2021-22", Maharashtra contributes 10% of India's total CO_2 emission. The automobile sector in Maharashtra is responsible for 12% CO_2 emission in the state (2021-2022). The state consumes approximately 90 MMT of petroleum product per year. Maharashtra contributes 310 MMT (37.7 MMT from transport sector) GHG emission in 2021-22.

As environmental change and air pollutant become increasingly urgent issues, environmental concerns act a central role in driving the embracement of EVs. People of Maharashtra become conscious of the environmental advantages of EVs. Studies show that consumers exhibit a heightened inclination to embrace eco-friendly technologies when they recognise environmental degradation as a significant issue (Reddy et al. 2023). Existing studies have underscored the necessity of integrating the environmental benefits of electric vehicles with transparent dissemination of information regarding their emission reduction capabilities, acoustic pollution mitigation, and overall carbon footprint diminishment. (Aderibigbe et al. 2023).

In response to the adverse environmental impacts of fossil fuel-based transportation, the state government has recognized the importance of transitioning to cleaner alternatives, such as EVs.

3.4. EV INITIATIVES IN MAHARASHTRA

The Maharashtra Electric Vehicle Policy 2025 is one of the key initiatives aimed at boosting EV adoption by offering incentives such as subsidies, tax benefits, and infrastructure development support.

Table 3.3: Policy Support and Initiatives, Maharashtra

Type of vehicle	Subsidy on Purchase new vehicle (Rs.)	Incentive on road tax and registration fee (Rs.)	Incentives on scrapping of vehicle (Rs.)
Battery Electric two-wheel vehicles	10000	Complete exemption	7000
Battery Electric three-wheel vehicles	30000	Complete exemption	15000
Battery Electric car	150000	Complete exemption	25000
Battery Electric bus	2000000	Complete exemption	25000

Source: Maharashtra EV Policy 2021

In Maharashtra, where long-distance travel is common due to the large urban-rural divide, consumers are particularly concerned about the range anxiety associated with EVs. While the state has made progress in developing charging infrastructure, there are still concerns regarding the adequacy and accessibility of charging stations, especially in rural areas. As per Twesh Mishra report in the Economics Times 06 Feb 2024, Maharashtra has only 3079 operational stations. The establishment of a comprehensive charging network, featuring rapid charging facilities, is pivotal in boosting consumer confidence in electric vehicles. Research by Ragavendran et al. (2023) also emphasized the importance of addressing range anxiety and ensuring that charging stations are distributed in a manner that supports long-distance travel. Social influence from family, peer groups and local communities can stimulate a considerable amount of motivation for the embracement of electric vehicles. (Manca et al. 2019; Shriwastavet al. 2024 and Patel et al. 2024). Additionally, Maharashtra's automotive culture, which is deeply rooted in traditional fuel-based vehicles, may contribute to consumer resistance. Research by Krishna, (2021) highlighted notably low consumer acceptance of new engineering innovation despite growing awareness. The adoption of EVs faces resistance due to ingrained consumer preferences for familiar vehicles and reluctance to adopt newer technologies (Tarei et al. 2021)

Notwithstanding substantial initiatives, the incorporation of electric vehicles in Maharashtra lags significantly behind conventional vehicles. As per JMK Research & Analysis FY 2024, Maharashtra has approximately 37.78 million automobile vehicles and cumulative EV sales in Maharashtra is only 0.376 million. Out of the 0.376 million EV, 0.322 million are two-wheeler electric vehicles. Therefore, EV adoption as compared to conventional vehicles is very less and needs immediate attention Maharashtra has 12% – 15% share of country's total vehicle sales.

Understanding the motivations behind EV adoption in Maharashtra is critical to addressing the barriers that hinder its widespread acceptance. These incentives are influenced by a multifaceted array of factors encompassing environmental apprehensions, governmental regulations, fiscal incentives, technological progress, and societal attitudes. Despite a substantial corpus of research on the embracement of electric vehicles in India, several knowledge lacunae persist in the existing literature when it comes to understanding the motivations behind EV adoption specifically in Maharashtra. Several studies have addressed national-level factors, such as consumer awareness (Tupe et al. 2020), financial incentives (Kohli, 2024; Shah, 2022), and the role of infrastructure (Kore et al. 2022). However, much of the research has been generalized and lacks a region-specific analysis of the unique socio-economic, cultural, and infrastructural challenges faced by consumers in Maharashtra.

Electric vehicle adoption in Maharashtra represents a critical step towards reducing the state's carbon footprint and improving urban air quality. The motivations behind EV adoption are complex and multifaceted, involving environmental concerns, economic incentives, technological advancements, and social factors. While significant progress has been made through government policies and incentives, several barriers remain, including high purchase costs, insufficient charging infrastructure, and cultural resistance.

Current research on EV embracement in India has predominantly concentrating on national-level trends with generalizations, leaving room for more region-specific studies that account for local socio-economic, cultural, and infrastructural factors. Addressing these research gaps through targeted studies

shall provide meaningful deep understandings to lawmakers, businesses, and other stakeholders to compose effective strategies for accelerating EV adoption in Maharashtra. Such efforts will be crucial in positioning the state as a leader in sustainable transportation in India.

Chapter 4

Models, Data Sources and Estimation Methods

CHAPTER 4
MODELS, DATA SOURCES AND ESTIMATION METHODS

Present chapter has been designed to discuss in detail the methodology and data processing techniques to predict adoption intention towards the purchase of Electric Vehicles and to estimate their impact on carbon emission reduction and fossil fuel consumption.

4.1. RESEARCH PARADIGM

A research paradigm can be defined as a set of common assumptions and beliefs on epistemic, methodological, and ontological concerns within a community of researchers. This philosophical framework is a theoretical construct that affects and constructs how researchers view their area of study. A research philosophy or paradigm addresses ontological questions about the essence of fact, the existence of entities, the interaction between them, and how they communicate (Martinez et al., 2017). There are two paradigms, namely positivism and interpretivism strategies, to gain expertise and relevant knowledge in the field of research. In the domain of the natural sciences, positivism is a philosophy of research. This philosophy highlights that the questions being examined are subject to subjective and objective scrutiny, and the findings can be dealt with in a reliable manner (Delucchi and Lipman (2001); Dhar et al., (2017)). Interpretivism relies on the ontology of constructivism. The interpretivists believe that human interaction imposes and builds the social world, and the social world is not already present (Dhar et al. (2017)).

The current study will use a positive research philosophy since it involves the use of a questionnaire method. The positive approach involves scientific and mathematical calculations. The study will aim to examine the research and understand the perceptions of individuals towards the embracement of EVs among Indian consumers. To collect requisite data from participants, the investigator intends to disseminate standardized closed-ended surveys amongst customers, thereby gaining insight into their perceptions concerning the adoption of electric vehicles within the Indian market.

4.2. RESEARCH APPROACH

To formulate the solutions to the research question and reach a practical conclusion from the research, the research process may be elucidated as a method of collecting data, analyzing the data gathered, and interpreting the data analyzed. Unfortunately, the research methodology is at times mistaken for the reporting system and data processing strategy [34]. The research process is initiated once the investigator starts dealing with the basis and existence of the selected research process. Study requirements will contribute to the adoption of the required testing methodology Donnellan, (2013). There are three research approaches: qualitative, quantitative, and mixed methods. The primary research studies using the quantitative method are those where results need to be analyzed mathematically. Statistics and statistical methods are applied to quantitative analysis, and surveys are used to gather the data (Egede et al., (2015). According to another scholar, the quantitative approach is primarily used to describe theoretical and scientific principles (Egede et al., (2015). Qualitative researchers are those individuals who engage themselves in self-questioning and self-comprehension even after being aware of their cultural and political opinions (Egnér&Trosvik, (2018). According to Jackson, the qualitative research approach is often referred to as a comprehensive and subjective research approach that results in discovery. The mixed approach is defined as an extension of each of the approaches to reduce the disadvantages and, at the same time, improve the efficiency of quantitative and qualitative research approaches (Egede et al., (2015). The idea of a mixed approach is considered to incorporate both methods into a single study. Both approaches are combined to better understand the world (Ellen et al. (1991).

The current research study will adopt a mixed-methods research approach for the collection of data. The objective of the study is to measure the effect of electric vehicles on the Indian automotive industry. Moreover, the study aims to explore the preferential inclinations and mindsets of individuals towards the embracement of EVs in India and to point out the factors contributing to the growth of EV acceptance in the Indian automotive sector. A quantitative

questionnaire survey will be administered to consumers in order to elucidate their cognitive perceptions pertaining to the adoption of electric vehicles (EVs) in the Indian market, and to identify salient factors contributing to the burgeoning adoption of EVs in India. Additionally, interviews will also be conducted with the employees above the managerial grade in the Indian automotive sector to know their opinions regarding the impacts of EV adoption on the Indian automobile industry.

4.3. RESEARCH DESIGN

Creswell (Emmel (2013) has defined research method as the system of making a master plan in such a way that all the factors that might impact the validity of research can be controlled or their impact can be minimized. Research design is efficient in determining the procedure for data collection and analysis. The research design can further be divided into four subcategories: descriptive research design, experimental design, exploratory design, and explanatory research design. In terms of testing defined hypotheses, experimental research designs are important and can offer valid conclusions between independent and dependent variables specified in the research assumptions. In general, the experimental design has a conceptual framework that is followed by the actual experiment conducted (Englberger et al. (2019)). As its name implies, the objective of exploratory research is to pointout and analyze the subject's experience to determine specific research issues and variables (Etikan (2017)). Analyzing the goals and priorities of the project by defining the following problems at the selected event is part of an exploratory research strategy. A descriptive research design, on the other hand, gives a sense of the process as it discreetly happens. Descriptive research is intended to explain existing procedures and promote new ideas (Faisal, (2017). After the collection of the data, the hypotheses are formulated. There are also certain observations based on social perceptions, as mentioned by McNabb (2012). Another research strategy is the explanatory approach, which is utilized when there are hypothesized, excessively challenging causal links between the real

interventions and the experimental strategies and plans that are unable to be interpreted.

The present work will use a statistical research design and an exploratory research design in order to fulfill the objectives of the research undertaken. The descriptive research design will be used to comprehend the conceptions and opinions of users and managers regarding the embracement of EVs in Indian context. The exploratory research will be performed to determine the causes that affect the growth of EV adoption in Indian automotive sector.

4.4. METHODOLOGY FOR RESEARCH OBJECTIVE-I

Theoretical Framework

Theory of Planned Behaviour

The sustainable development goals underscore the vitality of generating clean energy and its application across multiple sectors (Ikram et al., 2021; Shalender& Sharma, 2020). To minimize CO_2 emissions, automobile market and markets of other vehicles that function on sustainably acceptable fuel has yet not grown significantly (Kopelias et al., 2019). While consumers persist to demand conventional fuel vehicles, with governments and automobile sector are significantly investing in electric vehicles (Nouni et al., 2021; Deb et al., 2018; Deb et al., 2019). Electric vehicles produce numerous beneficial effects, such as enhanced utilization of renewable energy, sustainable consumption, and environmental protection. Nonetheless, various physical (limited short-term batteries, inadequate charging station infrastructure, etc.) and psychological (elevated vehicle costs, insufficient technological understanding, etc.) factors obstruct the adoption of electric vehicles (Franke et al., 2011; Machado et al., 2023; Javanmardi et al., 2023). Research on electric vehicles examines the behaviors of users to eliminate these obstacles. The behavioral analyses encompass multiple theories, including the widely sought-after theory of planned behavior (TPB).

Ajzen (1985) devised the Theory of Planned Behaviour (TPB) in the realm of psychology, stating that the precise forecasting of intentions regarding different behaviors can be attained through attitude, subjective norm and perceived

behavioral control. The TPB can ascertain consumer's buying intentions for a product or service, along with the rationale underlying their brand selection (Ajzen, 1991). Of which an attitude indicates an individual's acceptance of a specific behavioral habit (Hagger et al., 2022; Ajzen, 1991), while subjective norms, indicates the social pressure encountered by an individual when partaking in or abstaining from a specific behavioral habit (Morren & Grinstein, 2021; Ajzen, 1991) and perceived behavioral control entails assessing the ease or difficulty of undertaking a specific behavioral habit (Hagger et al., 2022; Manstead& Parker, 1995; Ajzen, 1991).

Extended Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) is extensively employed in studies concerning environmentally conscious habits. Previous studies on electric vehicle purchase intention have linked TPB to numerous dimensions, including green trust, environmental concern, willingness to pay a premium, and moral norms. Studies have subsequently employed these extended theories of planned behavior to construct broader predictions on behavioral traits that may facilitate adoption of environmentally friendly fuel-efficient transport vehicles, such as electric vehicles (EVs). Numerous research has shown that the Theory of Planned Behaviour (TPB) or the Extended Theory of Planned Behaviour (ETPB) can effectively evaluate consumer's electric vehicle purchase intention (Wang et al., 2014; Shalender& Sharma, 2020; Zhang et al., 2018; Yeğin& Ikram, 2022; Kaplan et al., 2016; Asadi et al., 2020).

Determinants of Extended Theory of Planned BehaviourAttitude

Attitude is the initial component specified in the TPB and pertains to the investigation into the intention to adopt a product (Shalender& Sharma, 2020; Kim & Han, 2010). It refers to individual's positive or negative assessment of certain habits based on observation, experience etc., and the desire to engage in that habit (Abbasi et al., 2022; Bianchi, 2016). If a consumer perceives the product in a positive manner, its probability of acquiring it rises (Ajzen, 1991; Beck & Ajzen, 1991). Several studies across multiple geographical regions, encompassing various themes and titles, substantiate this assumption (Abou-Zeid & Ben-Akiva, 2012; Kim & Han, 2010; Yeğin& Ikram, 2022; Asadi et al.,

2020). The construct of attitude is viewed as the primary determinant to evaluate people's electric vehicle purchase intention (Mukesh & Narwal, 2023; X. Wang et al., 2021; S. Wang et al., 2014; Li et al., 2018). Individuals with positive perspective towards EVs are more inclined towards purchasing of it as compared to consumers with negative perspective, thereby showcasing that attitude significantly influences consumer's intention towards the acquirement of electric vehicles (Singh et al., 2020; Hsu et al., 2017; Egbue& Long, 2012). Studies indicate that individuals exhibit an emotionally favorablebehavior towards attaining electric vehicles due to factors such as their lower fuel costs, quieter engines, reduced environmental impact, enhancement of social status and more, while certain studies have even identified negative perceptions with respect to the functional attributes of electric vehicles, which arise from perceived functional barres including restricted range, insufficient charging infrastructure, prolonged charge durations, etc, (Morton et al., 2016; Schmalfuß et al., 2017; Skippon et al., 2016; Lashari et al., 2021; Bryła et al., 2022; Rezvani et al., 2014).

Subjective norm

It is characterized by social pressure than an individual experiences to behave in manner that is acceptable in the society (Ajzen, 1991). Social norms are defined as an individual's perception of the values held by friends or family, regarding that of an individual's behavior (Adnan et al., 2017), while some studies stated that social norms tend to indicate that an individual considers the social expectations before engaging in their behavior, which generates societal pressure on them (Y. Zhang et al., 2021; Yeğin& Ikram, 2022; Setiawan et al., 2020). Numerous studies have demonstrated a positive association between experiencing social pressure and behaving in an appropriate manner (Vafaei-Zadeh et al., 2022; Chukwuma, 2023; Wu et al., 2020; Shalender& Sharma, 2020), which as a result acknowledges subjective norms as a determinant of adoption intention (Gong et al., 2019; Chu & Chen, 2015). Studies indicate a lack of association between the intention of adoption of electric vehicles and subjective norms while on other hand it has been noticed that social norms guide the buying behavior of individuals about electric cars in China (S. Wang et al., 2014; Han et al., 2015; Chen & Hung, 2016; Xie et al., 2022).

Perceived Behavioral control

The third determinant of TPB, which is perceived behavioural control (PBC), outlines the ease or difficulty of an individual's interaction in a certain behavioural manner (Ajzen, 1991). The PBC demotes the impact of external pressures on an individual, regarding their specific behaviour, it showcases their broad evaluation of ease or difficulty associated with the conduct of their behaviour (Javid et al., 2022; Adu-Gyamfi et al., 2022; Lai et al., 2015). The research addressing the adoption of electric vehicles, perceived behavioural control was significantly determined as a predictors of consumer's pro-environmental behaviour (Yadav & Pathak, 2016; Lane & Potter, 2006). Traditional theory of planned behaviour model directly examines the impact of perceived behavioural control on behavioural intention, with research on electric vehicle adoption examining this direct impact. PBC has been seen as the most significant determinant of EV buying intention in Norway, and India (Egbue& Long, 2012; Shalender& Sharma, 2020).

Environmental concern

Environmental concern indicates the extent of awareness among consumers regarding the issues of climate change and their willingness to be a part of the solution (Tobler et al., 2012; Bamberg, 2003) and it is among one of the significant factors that tends to influence the behaviour of a consumer (Han, 2021; Dutta & Hwang, 2021; S. Wang et al., 2017). Individuals that possess significant environmental consciousness are inclined towards the implementation of measures that would safeguard the environment and in addition, diminish their ecological footprint via making alteration to their lifestyles and adopting a lifestyle with low-carbon footprint (Lubowiecki-Vikuk et al., 2020; Axsen et al., 2018; Rezvani et al., 2014; Howell, 2012). Numerous studies have validated that consumer's concern towards environment influences their buying behaviour of eco-friendly products and has emphasized towards the vitality of environmental concern determinant in anticipating this behaviour as compared to non-environmentalist (De Canio et al., 2021; Wei et al., 2017; Sun et al., 2017; (Sharma et al., 2022; Kahn, 2007). Research directed towards electric vehicle, the determinant of environmental concern is assessed by enquiring consumer's perspective towards climate change being a major threat

and if they are willing to contribute towards its solution (Anastasiadou &Gavanas, 2022; Dutta & Hwang, 2021; Egbue& Long, 2012). Research have posited electric vehicles as eco-innovations with the potential to mitigate adverse environmental consequences, given their ecological advantages (Seth et al., 2023; Requia et al., 2018; Bonges& Lusk, 2015). Study carried out by S. Wang et al. (2014) used extended theory of planned behaviour to predict consumer' intention towards buying of electric vehicles and deduced that environmental concern greatly influences the adoption intention. Studies further demonstrate that consumers with greater awareness towards climate change are willing to pay a premium for low-emission vehicles and are more inclined towards the purchase of electric vehicle (S. Wang et al., 2017; Costa et al., 2018; Ma et al., 2019; Anastasiadou &Gavanas, 2022).

Technological factor

The tends in technological adoption demonstrate that though new technology is inherently enticing to selected group of early consumers, the rest of the consumers demonstrate a rather close-minded opinion towards the adoption (Egbue& Long, 2012; Lee et al., 2003; A. Sharma & Gandhi, 2023). It has been noted that many consumers experience discomfort with advances in technology and their associated uncertainty, which leads towards the unwillingness of technological adoption, with majority of consumer favouring conventional and traditional products (Ahmad et al., 2022; Guney, 2018; Edison & Geissler, 2003; Sovacool& Hirsh, 2008; Formilan&Boari, 2021). The technological developments are going to persist towards the enhancement of safety, performance and the range of electric vehicles, yet consumers perspective towards these attributes remain crucial for researcher and even practitioners to gain insight (Dutta & Hwang, 2021). Empirical research has demonstrated that automobile performances is vital, alongside both social and environmental factors (Chng et al., 2019; Inkpen & Baily, 2019). Studies revealed that early consumer adopter had more awareness towards environmental consideration, however, the reliability, safety, purchasing cost along with the driving range of the vehicles had become the most dominant determinant towards the adoption (Egbue& Long, 2012; Jiang et al., 2021; Carley et al., 2012).

Policy and support

Policy initiatives are implemented to enhance the desirability of electric vehicles, which results towards a positive impact towards its adoption (Langbroek et al., 2016; X. Zhang et al., 2014; Sierzchula et al., 2014). Government policies can facilitate electric vehicle adoption by either supply-side measure (such as subsidies, incentives) or by demand-side strategies (such as enhancing profitability) (Lu et al., 2020; Jenn et al., 2018; Sovacool, 2010). Governments globally give priority to financial incentives in order to persuade the consumers towards adoption of electric vehicles as they are ecologically sound and economically viable, with tax incentive being the primary financial incentive, as 10% increase in total tax incentive leads to sales of EV share by 3% on average (Yan, 2018; Langbroek et al., 2016; Sierzchula et al., 2014; Ansab & Kumar, 2022; Shafiei et al., 2018). Prior studies have suggested financial incentives form governments or manufactures greatly influences consumer behavioural intention towards electric vehicle adoption (Ansab & Kumar, 2022; Huang & Ge, 2019; Jaiswal et al., 2021). The government incentives act as an antecedent factor of perceived behavioural controls, as government greatly influences the expansion of automobile sector (Huang & Ge, 2019; Xue et al., 2021; X. Wang et al., 2021). The lack of financial incentive will dampen consumer's excitement towards adoption of electric vehicle, whereas governments incentives such as tax benefits, economic subsidies, favourable loan policies and enhancement of electric vehicle infrastructure, will motivate consumers towards adoption of this new automobile (Huang & Ge, 2019; Ansab & Kumar, 2022; N. Wang et al., 2018).

Hypothesis Development

The study's theoretical framework (Fig. 4.1) and existing literature have led to the formulation of the following hypotheses:

H1: The intention to adopt electric vehicles (EVs) is positively correlated with the adoption attitude.

H2: The inclination to embrace EVs is strongly correlated with the effect of subjective standards.

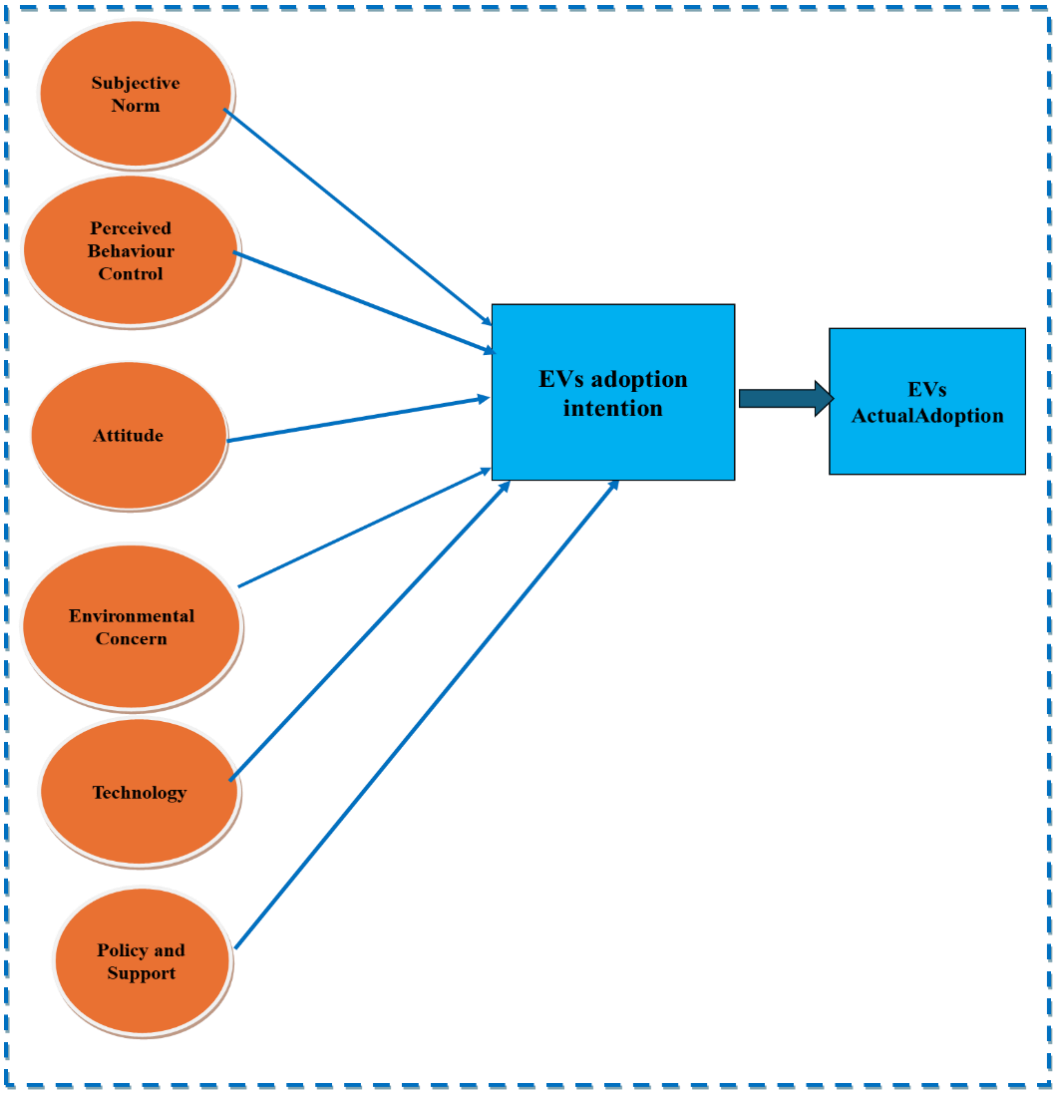
H3: The intention to switch to electric vehicles is positively correlated with perceived behavioural control.

H4: The inclination to switch to electric vehicles is positively correlated with environmental concern.

H5: There is a positive relationship between policy measures and EVs adoption intention.

H6: Adoption of electric vehicles (EVs) is positively influenced by technological advancements.

Figure 4.1: Theoretical framework.



Sampling Technique

The current study has adopted a non-probability sampling method for choosing respondents for the questionnaire survey. In this study, considering the practical

constraints we used convenient sample technique covering purposively the two-wheeler, three-wheeler and four-wheeler vehicles.

Sample Size

According to census 2011Given the population frame sample size of 390 respondents were chosen following Cochran (1999):

$$n_0 = \frac{pqz^2}{e^2} \quad (1)$$

and

$$n = \frac{n_0}{1 + (\frac{(n_0 - 1)}{N})} \quad (2)$$

Where, p = 'Yes' responses (67.2%) from the pilot survey conducted

q = 'No' response (32.8%) from the pilot survey conducted

z = standardized normal distribution table (95% confidence level with a z value of 1.96)

e = admissible error level (5% level of error i.e. e =0.05)

n_o = Rough sample size

n = finite population correction (FPC)

N= Total population

Rough sample size calculated as 334(p=67.2%, q=32.8%, e=0.05 and z=1.96)

Data Collection

A survey questionnaire was employed in this study to examine the hypotheses discussed in the section and figure. With an 82% response rate, 390 of the 474 customers were contacted back. In accordance with the recommendations of Hill et al. (1997) and Armstrong and Overton (1977), the study performed a test for non-response bias. To determine the precise number of respondents who had returned the questionnaire, we gathered demographic and social data from the participants during distribution. We divided the responses into three groups based on the information we received: (1) accurate respondents (those who entirely completed the questionnaire), (2) inaccurate respondents (those who

returned the incomplete questionnaire), and (3) non-respondents (those who did not return the questionnaire). Data was collected both online (using google link) as well as face-to-face.

Measures

The scales used in previous studies were modified to fit three catalogues of policy measures (Coad et al., 2009; Ozaki and Sevastyanova, 2011). Four items were used to measure each policy measure. A few of the scale elements' wordings were slightly changed to reflect the adoption of EVs. The environmental concern was measured using five different items. They were modified from the writings of Zhang et al. (2013), Ramayah et al. (2010), and Fujii (2006). Three questions that were modified from the research of Zhang et al. (2013) and Ramayah et al. (2010) were used to measure the intention to adopt. A 5-point Likert scale, ranging from "strongly disagree" to "strongly agree," was used to score each assessment item. Appendix A contained a list of these measurement items.

Construct	**Scales adapted from**
Environmental Concern	Fujii, 2006; Ramayah et al., 2010; Zhang et al., 2013).
Attitude toward adopting an EV	Lopes et al. (2019), and Matsumori et al. (2019).
Subjective Norm	Zhang et al. (2020).
Perceived behavioural control	Han and Hyun (2017).
Perceived behavioural control	Han and Hyun (2017).
Intention to adopt an EV	(Ajzen, 1991; Ramayah et al., 2010; Zhang et al., 2013).
Policy and Support	Wang et al., 2017.
Technological Factors	Khan et al., 2018.

Software

The data for the study's objective were analysed using IBM SPSS version 23.0 and SMARTPLS version 4. Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) were performed using SMARTPLS 4.0, whereas exploratory factor analysis (EFA) and normality testing were performed using SPSS

23.0. Descriptive statistics, logit model estimation and other robustness checks were performed using STATA 14.

Diagnostics

Normality

A characteristic of the normal distribution, often known as the bell curve or Gaussian distribution, is normality. In a normal distribution, the data is symmetrical with respect to the mean and standard deviation and fluctuates over a continuous curve. Figure 3.3 displays the normal distribution curve needed to analyse normal data. The sample data's conformance to a normal distribution is ascertained using the normality test. Normalcy was evaluated using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The null hypothesis asserts that the data are regularly distributed for both tests. Normality is shown by a significance level (p-value) more than 0.05, but a p-value less than 0.05 implies that the data does not follow a normal distribution.

"Kaiser-Meyer-Olkin (KMO)"

The KMO value evaluates data's suitability for factor analysis. The range of a KMO value is 0 to 1. Greater values suggest that factor analysis will probably be beneficial.

Total Variance

The Kaiser Criterion states that only elements with eigenvalues higher than one are deemed relevant. All components in our case have eigenvalues greater than one and are kept for additional examination. The cumulative variance of 60% or more is typically regarded as sufficient and all the components account for 60.378% of the overall variation.

Robustness Check

The Logit model in this case has been used (because of its mathematical convenience) to identify socio-economic, demographic and other such factors that affect the dichotomous choice of willingness to shift to EV. Therefore, the probability that the i^{th} respondent is willing to shift to EV is:

$$Prob(Y = 1|X) = F(X_i, \beta') = P_i = \frac{e^{z_i}}{1 + e^{z_i}}$$

Z_i is a linear function of *n* explanatory variables (X_i), and expressed as:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \beta_n X_{ni}$$

If P_i is the probability that the i[th] household is willing to shift, then $(1 - P_i)$, the probability of not willing to shift, is

$$1 - P_i = \frac{1}{1 + e^{z_i}}$$

Therefore, we can write

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{z_i}}{1 + e^{-z_i}} = Z_i$$

Where $P_i/(1 - P_i)$ is the odds ratio or the ratio of the probability that a respondent is willing to shift to the probability that a respondent is not. Taking the natural logarithm, we get the log of the odds ratio, which is known as Logit model:

$$L_i = \ln\left(\frac{P_i}{1 - P_i}\right) = \ln(e^{z_i}) = Z_i$$

If the error term (ε) is considered, the Logit model becomes:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 S X_{3i} + \cdots + \beta_n X_{ni} + \varepsilon$$

Where, β_0 is an intercept which tells us the log-odds in favor of shifting to EV when the coefficients of all included explanatory variable are assumed to be zero. $\beta_{1 \to n,}$ are slope parameters to be estimated in the model, respectively. The slope tells how the log-odds in favor of willingness to shift to EV change as each independent variable changes. Z_i is also referred to as the log of the odds ratio in favor of EV adoption. In the present study, the above econometric model (here, the *equation 5*) has been used to identify factors affecting the WTS of a respondent by using the iterative Maximum Likelihood Estimation Procedure. To test the reliability and overall fitness of the Discrete Choice Model (like the current case), the Likelihood Ratio Chi-square test has been used (Mukherjee, et al., 1998).

4.5. METHODOLOGY FOR RESEARCH OBJECTIVE-II

Theoretical framework

Comparative Life Cycle Assessment approach has been used for assessing carbon emission associated with all the stages of the life cycle of ICE vehicle and EV.

Life Cycle Assessment (LCA)

The society of Environmental Toxicology and Chemistry (SETAC) held a workshop in the USA during 1990 wherein the term Life Cycle Assessment (LCA) was first used (Sjöqvist et al. 2021). Three interrelated components i.e. Inventory analysis, Impact analysis and Improvement analysis were used by SETAC in the LCA framework. International Standard Organization (ISO), a self-dependent, non-governmental international organization consists of standard bodies from more than 160 countries was established in1947 in London to develop and publish guidelines and regulations for services, systems, products and processes (Wikipedia ISO). ISO 14040 was published in 1997 that described the principle and framework of LCA. ISO 14044 was published in 2006 which outlined guidelines for conducting LCA. As per ISO 14040 and ISO 14044, LCA of any product or system is the quantitative analysis of its environmental impact from raw material utilization to the disposal or recycling of the system.

Goal and Scope Definition

This stage sets the objectives and boundaries for the analysis. The scope depends on the product or service in question and the complexity of its supply chain. Broader system boundaries can highlight key processes that contribute significantly to environmental impacts. The system boundary determines which activities to include based on predefined criteria and intended outcomes. Using a functional unit as a reference, analysts ensure consistency when comparing systems. The chosen analysis period is also crucial, as shifts in energy use or production practices over time may influence results. Reliable data underpins the credibility of any LCA.

Inventory Analysis: During this phase, material and energy flows within the system are quantified. Key steps include:

Developing a flowchart that outlines the raw materials, manufacturing processes, transportation, usage, and waste management.

Collecting data on inputs, outputs, by-products, and emissions (solid, liquid, and gaseous).

Calculating the relationship between these factors and the functional unit.

Impact Assessment: The environmental effects identified during the inventory analysis are measured. Common impact categories include climate change, freshwater eutrophication, ozone depletion, land-use changes, and human toxicity.

Interpretation: This final phase integrates and evaluates results from all stages. The findings are scrutinized for reliability and are summarized clearly to support decision-making. This step is essential for instilling confidence in stakeholders and ensuring effective communication of the results.

Types of Life Cycle Assessments: Depending on the scope and purpose, LCAs can follow various approaches:

- **Cradle-to-Gate**: Focuses on raw material extraction up to the factory gate, omitting usage and end-of-life phases.
- **Cradle-to-Grave**: Offers a complete view, covering the product's lifecycle from raw materials to final disposal, including maintenance and recycling.
- **Cradle-to-Cradle**: Promotes circularity by reintroducing waste and by-products into the raw material stage, encouraging sustainability and corporate responsibility.

For transportation fuels, a Well-to-Wheel approach evaluates energy use and emissions, further divided into:

- **Well-to-Tank**: Examines energy production and storage.

- **Tank-to-Wheel**: Assesses energy conversion during vehicle operation.

To assess the impacts of EV adoption in Indian automotive sector in terms of fossil fuel consumption. Comparative Life Cycle Assessment approach has been used in this case. Life Cycle Assessment is a methodology for assessing environmental impacts associated with all the stages (manufacturing, use and end to life) of the life cycle of a product, process or service. A questionnaire survey has been conducted among the driver/user of related EV and ICE vehicles. The data related use stage has been gathered based on survey method and balance data has been gathered from secondary sources like research article, journal, govt and private web site. The responses have been analyzed using the LCA model concept. All calculations have been carried out in MS Excel.

Conceptual Model

Comparative life cycle assessment concept has been used to achieve research objective II. Carbon emissions occurred in complete life cycle of IC engine vehicle and electric vehicle have been assessed separately and then total car bon emission by both type of vehicles are compared. Accordingly net carbon emission reduction due to adoption of electric vehicle is assessed. Functional unit considered for life time distance covered by a vehicle in Km. Four types of vehicle considered here i.e., two wheelers, three wheelers, car and bus. Life of two wheelers both IC engine and electric vehicle are considered as 90,000 Km. Life of three wheelers both IC engine and electric vehicle are considered as 288,000 Km. Similarly, life of car both IC engine and electric vehicle are considered as 150,000 Km. Life of bus both IC engine and electric vehicle are considered as 720,000 Km. Functional unit of life time carbon emission for all types vehicles is considered in Kg. Life time carbon emission for a IC engine vehicle is obtained by summing carbon emission from all sub cycles of each cycle i.e., vehicle production cycle, fuel cycle, battery cycle and operation cycle. Similarly life time carbon emission from a battery electric vehicle is obtained by summing up carbon emission from all sub cycles of each cycle i.e., vehicle production cycle, power cycle, battery cycle and operation cycle. Finally carbon

reduction due to EV adoption is obtained by subtracting life time carbon emission of a battery electric vehicle from that of a conventional engine vehicle.

Carbon emission component of each type of vehicle are described in succeeding paragraphs.

A Life Cycle Assessment evaluates the environmental impacts associated with all stages of a vehicle's life, from raw material extraction to disposal or recycling. For an Internal Combustion Engine (IC) vehicle, the LCA can be divided into several sub-cycles: **Vehicle Cycle**, **Fuel Cycle**, **Battery Cycle**, and **Operation Cycle**. Vehicle cycle consists of various stages such as raw material extraction/mining, part manufacturing, assembling, vehicle production, use/maintenance and end of life. Battery cycle consists of raw material extraction/mining, transportation, battery manufacturing, charging/power consumption, use by vehicle and disposal/recycling/reuse etc. Fuel cycle consists of fuel/crud extraction, transportation, oil refining, oil distribution, use by vehicle and recycling/reuse etc. Operation cycle consists of use/maintenance of vehicle production, battery use by vehicle and fuel use by vehicle etc.

A Life Cycle Assessment (LCA) for a Battery Electric Vehicle (BEV) also evaluates the environmental impacts associated with all stages of a vehicle's life, from raw material extraction to disposal or recycling.. The LCA of a BEV can be divided into key sub-cycles: **Vehicle Cycle**, **Power Cycle**, **Battery Cycle**, and **Operation Cycle**, with detailed processes within each sub-cycle. Vehicle cycle consists of various stages such as raw material extraction/mining, part manufacturing, assembling, vehicle production, use/maintenance and end of life. Battery cycle consists of raw material extraction/mining, transportation, battery manufacturing, charging/power consumption, use by vehicle and disposal/recycling/reuse etc. Power cycle consists of fuel/ extraction, transportation, power generation, power distribution, and use by vehicle etc. Operation cycle consists of use/maintenance of vehicle production, battery use by vehicle and fuel use by vehicle etc. A systematic understanding of these stages provides a holistic view of emissions associated with both vehicle types. All sub-cycles and their various phases of conventional internal combustion engine vehicles (ICEVs) are discussed below:

4.5.1. VEHICLE PRODUCTION CYCLE

This sub-cycle encompasses all activities from raw material extraction to vehicle assembly and end-of-life processing.

Material extraction: Mining of raw materials, refining and processing materials into usable forms like iron, aluminum, copper, plastics and rare-earth elements used for components such as the engine, body, transmission, electrical parts, other sub assemblies, tyre, tube, flap rest and lubrication oils such as engine oil, gear oil, brake fluid etc. Each of these items contributes to carbon emissions through extraction, refining, and manufacturing**. Steel & Cast Iron** produces emissions from diesel-powered mining equipment, transportation, and high-temperature smelting in blast furnaces using coal-derived coke. **Aluminum** consumes high energy in refining bauxite to alumina and electrolysis in smelting leads to significant emissions, especially when powered by fossil fuels. **Copper** for mining, smelting, and refining processes require high energy inputs, often powered by coal or diesel that results CO_2 emission. Natural rubber production involves deforestation and processing with fossil fuel energy resulting carbon emission. Similarly synthetic rubber, derived from petroleum, emits CO_2 during refining and polymerization. **Plastic d**erived from crude oil and natural gas, plastic production releases emissions during extraction, refining, and polymer manufacturing. **Glass** involves melting silica sand at high temperatures in furnaces powered by fossil fuels contributes to emissions. **Lubrication oils produced from e**xtracting, refining, and processing lubricants release CO_2 from fossil fuel combustion. **Carbon Fiber** is highly energy-intensive process leading to carbon emission; carbon fiber production emits CO_2 due to high-temperature processing and fossil fuel-based electricity use.

Part/Component production: Producing individual vehicle parts like the engine assembly, clutch, transmission system, brake system, other sub assemblies and consumables and combining all parts into a finished vehicle in manufacturing plants. These multiple processes generate carbon emissions due to energy-intensive operations and material consumption. **Metal Cutting & machining** processes like milling, turning, and drilling require CNC machines

which are operated by electricity that generate carbon emissions. Coolants and lubricants used in machining add indirect emissions. **Welding** such as arc, laser, and resistance welding consume high electricity or gas, producing emissions from energy use and burning shielding gases. **Grinding & polishing** like abrasive grinding generates dust and heat, requiring electricity-powered equipment, contributing to emissions, especially when grid electricity relies on coal. **Casting & forging produces** melting metals in foundries and shaping them in forges require high-temperature furnaces, often powered by coal, oil, or gas, leading to significant CO_2 emissions. **Stamping & pressing** through hydraulic and mechanical presses use large amounts of electricity, while lubrication oils and metal treatments add to emissions. **Plastic Molding & Composite Processing** like injection molding and carbon fiber curing require high temperatures and fossil-fuel-based electricity, contributing to emissions.

Assembling: Final assembling of parts and testing involves robotic machines, quality checks, and functional testing that consumes electricity and compressed air etc., that indirectly emit CO_2. **Painting & Coating** such as Spray painting and electro-coating involve solvents and chemical curing, releasing volatile organic compounds and energy-intensive drying ovens all of which involves release of carbon emissions.

Transportation: Shifting materials and components between facilities by road, rail and ship etc. The transportation of automobile components and complete vehicles generates carbon emissions from fossil fuel combustion in various modes of transport. **Road transport** like diesel-powered trucks transport sub assemblies like engines, transmissions, chassis, and cooling systems between suppliers and factories. It emits CO_2 depending on distance, load weight, and fuel efficiency. Rail is more fuel-efficient than road transport but still emits CO_2 from diesel-powered locomotives. Electrified rail systems also produce emissions through power generation and transmission. Global supply chains rely on heavy fuel oil-powered ships to transport large components like transmissions, hydraulics, and complete vehicles. These ships produce significant CO_2. Occasionally, urgent sub-parts like electronics, fuel systems, and specialized components are air-freighted, generating high CO_2 emissions

per unit weight. Transporting lubricants, coolants, and fuel system components involves tanker trucks and ships, with emissions from both fuel combustion and evaporative losses.

Use/Repair & maintenance: Carbon emissions from the combustion process in internal combustion (IC) engine cylinders primarily consist of carbon dioxide (CO_2) and carbon monoxide (CO). When fuel burns inside the engine cylinder, carbon from the hydrocarbon fuel reacts with oxygen to form CO_2, a major greenhouse gas. However, incomplete combustion due to insufficient oxygen or improper fuel-air mixing results in the formation of CO, a toxic pollutant. Additionally, unburned hydrocarbons (HC) and particulate matter (PM) may also be emitted, contributing to air pollution. The level of emissions depends on factors such as engine efficiency, fuel type, combustion temperature, and emission control technologies. Carbon emissions from IC engine vehicle repair and maintenance activities arise from various direct and indirect sources. During maintenance, processes such as engine tuning, oil changes, and fuel system cleaning can release volatile organic compounds (VOCs) and hydrocarbons (HC) into the atmosphere. Repair activities involving welding, painting, or part replacements may also contribute to emissions. Additionally, energy consumption in service centers, disposal of used engine oil, and improper handling of worn-out components contribute to the overall carbon footprint.

Recycling/Disposal: Processing and recycling materials from scrapped vehicles to recover metals, plastics, and other components. The end-of-life processing of automobiles generates carbon emissions from transportation, dismantling, shredding, recycling, and reprocessing. Scrap vehicles are transported via diesel-powered trucks or rail to dismantling and recycling facilities, emitting CO_2 based on distance and load weight. Removing reusable parts and draining fluids requires energy for tools and handling, generating indirect emissions. Hydraulic shears and presses cut and compress vehicle bodies for easier transport and processing, consuming electricity or diesel-powered hydraulics, leading to CO_2 emissions. High-powered shredders break down metal and non-metal components, consuming large amounts of electricity, often derived from fossil fuels. Magnetic and eddy current separators sort materials, adding to

energy use. Steel, aluminum, and copper are melted in electric arc or induction furnaces, consuming significant energy. Emissions depend on electricity sources and fuel use in smelting. Plastics may be incinerated, emitting CO_2, or reprocessed, requiring heat and chemicals. Tire recycling involves shredding, pyrolysis, or repurposing, each with varying energy demands. Non-recyclable materials decompose in landfills, releasing methane and CO_2. Incineration produces additional emissions.

4.5.2. FUEL CYCLE

This sub-cycle evaluates the environmental impact of fuel production, distribution, and consumption.

Crude Extraction: Drilling and mining for crude oil generate carbon emissions at multiple stages, including extraction, processing, and transportation. **Exploration & site preparation** such as seismic surveys, land clearing, and road construction require diesel-powered equipment and offshore drilling rigs that consume large amounts of fuel for operations. All these operations emit CO_2. Oil drilling rigs, whether onshore or offshore, use diesel generators and machinery for drilling, pumping, and well maintenance, leading to direct CO_2 emissions. Enhanced oil recovery methods, such as gas injection, further increase emissions. Excess natural gas, often found with crude oil, is flared or vented emitting CO_2 and methane—both potent greenhouse gases. Extracting oil from tar sands or shale requires energy-intensive processes like steam-assisted gravity drainage or hydraulic fracturing, consuming fossil fuels and producing high emissions. Pipelines, tankers, and trucks transport crude oil from extraction sites to refineries, with emissions from fuel combustion in these transport systems. Handling produced water, drilling muds and waste gases involves additional energy use, contributing to emissions.

Transportation: The transportation of crude oil from offshore oil rigs to refineries is a significant source of carbon emissions. The primary sources include **marine transportation, pipeline operations, flaring and venting and leakages and spills.** Crude oil is often transported via tankers, which burn fossil fuels such as heavy fuel oil or marine diesel. The combustion of these fuels

releases carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur oxides (SO_x) into the atmosphere. Pipelines are another major mode of crude oil transportation. While they are more energy-efficient than tankers, they still require electricity or gas-powered pumps to maintain pressure and flow, leading to indirect CO_2 emissions, especially if the electricity is generated from fossil fuels. During loading and unloading, excess gas is sometimes flared or vented, leading to CO_2 and methane (CH_4) emissions. Methane is a potent greenhouse gas with a higher global warming potential than CO_2. Accidental leaks and spills during transport contribute to emissions through the release of volatile organic compounds (VOCs), which can form ground-level ozone and impact air quality.

Oil refining: Refining crude oil into gasoline or diesel and producing additives. Refining crude oil into gasoline, diesel, and additives generates carbon emissions through energy-intensive processes and chemical transformations. Refineries heat crude oil in distillation columns using fossil fuel-powered furnaces, emitting CO_2 from fuel combustion. **Cracking & reforming** processes like fluid catalytic cracking and hydro-cracking break down heavy hydrocarbons into lighter fuels, requiring high temperatures and hydrogen, often produced from natural gas, leading to CO_2 emissions. CO_2 releases for removing sulfur from diesel and gasoline that uses hydrogen, generated via steam methane reforming. Additives like ethanol, detergents, and octane boosters require energy-intensive chemical processing, adding to emissions. Ethanol and bio-fuels also involve land use and production emissions. Refineries operate large compressors, pumps, and cooling systems, relying on fossil fuel-based electricity and steam, increasing emissions. Excess gases are burned or released, producing CO_2 and methane emissions. **Waste & byproduct handling** processing residues, such as coke and sulfur, requires further handling and energy use, contributing to emissions.

Oil distribution: Delivering refined fuel to distribution centers and fueling stations. Delivering refined fuel to distribution centers and fueling stations generates carbon emissions through transportation, storage, and handling. Pipelines, the primary method for transporting gasoline and diesel, use electric or gas-powered pumps to move fuel over long distances, emitting CO_2

depending on energy sources. Pipeline leaks can also lead to indirect emissions. Fuel is transported from refineries or terminals to gas stations using diesel-powered tanker trucks, emitting CO_2 from fuel combustion. Emissions vary based on distance, load weight, and fuel efficiency. Diesel-powered trains transport large fuel quantities to regional distribution hubs, producing emissions from locomotive fuel combustion. Large tankers move refined fuel across oceans, burning heavy fuel oil and emitting CO_2. Fuel stored in tanks at distribution centers and fueling stations releases volatile organic compounds (VOCs), contributing to indirect carbon emissions. Vapor recoveries systems help reduce these losses. Fuel station pumps use electricity, often sourced from fossil fuels, generating emissions during dispensing.

Use by vehicle: Burning fuel in the engine during operation, contributing to emissions of CO_2. Burning fuel in an engine generates carbon emissions through combustion, incomplete fuel oxidation, and energy losses. Gasoline and diesel engines burn hydrocarbons and produced carbon dioxide (CO_2). The amount of CO_2 released depends on fuel type, engine efficiency, and driving conditions. Inefficient combustion leads to release of carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM) that contributes to air pollution. Processes like idling, stop-and-go traffic, and inefficient acceleration increase fuel consumption and emissions per mile traveled. Small amounts of methane and volatile organic compounds (VOCs) are released, especially in older engines or poorly maintained vehicles. Internal combustion engines waste energy as heat, reducing fuel efficiency and increasing CO_2 emissions per unit of useful energy. Catalytic converters and diesel particulate filters require additional energy, indirectly contributing to emissions.

Recycling/Reuse: The end-of-life phase of fossil fuels like diesel, petrol, and lubricants in internal combustion engine vehicles contributes significantly to carbon emissions. Re-refining and reusing lubricants involve energy-intensive processes that emit carbon dioxide and other greenhouse gases. Combustion of reclaimed fuels can still release CO_2, though slightly less than virgin fuels. Waste oil recycling and fuel reclamation require transportation, processing, and chemical treatments, all of which lead to CO_2 emissions. Some recycling

methods, such as distillation and re-blending, consume substantial energy, increasing their carbon footprint. Additionally, improper handling of used fuels may result in methane emissions. Disposal of residual fuels and lubricants contributes to emissions through incineration or uncontrolled burning, releasing CO_2, and CH_4. Land filling of contaminated oil can lead to anaerobic degradation, emitting CH_4. Overall, while reuse and recycling reduce the demand for virgin fossil fuels, they still contribute to carbon emissions.

4.5.3. BATTERY CYCLE

Material extraction: Although IC engine vehicles rely minimally on batteries (e.g., for starting, lighting, and ignition), assessing their lifecycle is critical. The extraction and processing of materials used in conventional vehicle batteries, such as lead, lithium, and nickel, contribute significantly to carbon emissions. Mining operations involve energy-intensive activities, including drilling, blasting, transportation, and refining, primarily powered by fossil fuels. **Lead**, commonly used in lead-acid batteries, is extracted through underground or open-pit mining. The smelting and refining process releases CO_2 and other pollutants, contributing to environmental degradation. Hard rock mining requires extensive crushing and heating, generating high emissions. Brine extraction is less energy-intensive but consumes large amounts of water, indirectly contributing to environmental stress. In particular, laterite nickel mining requires smelting at high temperatures, often using coal-powered plants.

Battery parts manufacturing: Producing batteries, including the processing of electrolytes, anodes, cathodes and assembly. The manufacturing of conventional vehicle batteries, including lead-acid and lithium-ion batteries, is highly energy-intensive and contributes significantly to carbon emissions. The key processes—raw material refining, electrode production, electrolyte preparation, and battery assembly—require substantial energy input, often sourced from fossil fuels. **Cathode and anode production** involves the processing of materials such as graphite. Refining these metals requires high temperatures, intensive chemical treatments, and energy-demanding steps like calcinations and solvent extraction, leading to significant CO_2 emissions. **Electrolyte production** includes the synthesis of sulphuric acid and other

solvents, which involve complex chemical processes that generate greenhouse gases. **Cell assembly** includes coating electrodes, drying, electrolyte filling, and sealing. These processes consume large amounts of electricity, particularly in climate-controlled environments necessary for safety and performance. The **battery formation and testing** phase, where cells undergo charging and discharging cycles, further adds to emissions.

Transportation/distribution: The transportation and distribution of lead-acid batteries for internal combustion engine vehicles contribute significantly to carbon emissions. The production of these batteries involves multiple stages, including raw material extraction, manufacturing, and distribution, all of which require extensive transportation networks. Lead, sulfuric acid, and other raw materials used in battery production are typically mined in one location, processed in another, and then transported to battery manufacturing facilities. This supply chain involves heavy machinery, trucks, ships, and trains, all of which consume fossil fuels and emit carbon dioxide. Once the batteries are manufactured, they are distributed to vehicle manufacturers, dealers, and service centers, further adding to the carbon footprint. Additionally, lead-acid batteries are heavy, requiring significant fuel consumption for their transportation. The logistics of battery recycling and disposal also contribute to emissions, as used batteries must be collected and transported to recycling facilities, often across long distances. Reducing the carbon emissions associated with lead-acid battery transportation requires optimizing supply chain logistics, using energy-efficient transportation methods, and promoting localized production.

Use by vehicle: Lead-acid batteries are widely used in internal combustion engine vehicles for starting, lighting, and ignition purposes. Although these batteries do not directly emit carbon dioxide during use, their charging process and lifecycle contribute to carbon emissions. The electricity used to recharge lead-acid batteries often comes from fossil fuel-based power plants, leading to indirect CO_2 emissions. In regions with a high dependency on coal and natural gas for electricity generation, these emissions can be significant.

Recycling/Disposal: Recovering valuable materials like lithium and cobalt or safely disposing of end-of-life batteries. The recovery of valuable materials such as lithium, cobalt, and nickel from end-of-life vehicle batteries involves energy-intensive processes that contribute to carbon emissions. Recycling and safe disposal are essential to minimize environmental impact, but these processes themselves require substantial energy input. **Mechanical recycling** involves shredding batteries to separate metals, plastics, and active materials. This process consumes electricity and generates CO_2 emissions, especially if powered by fossil fuels. **Pyro-metallurgical recycling** uses high-temperature furnaces to extract metals like cobalt and nickel. This method is highly energy-intensive and emits significant amounts of CO_2 and other pollutants. **Hydrometallurgical recycling** dissolves battery materials in acid solutions to recover lithium, cobalt, and other metals. Although this method has lower emissions than smelting, it requires chemical processing and wastewater treatment, contributing to indirect carbon emissions. **Direct recycling** aims to refurbish battery components with minimal processing, offering the lowest emissions.

4.5.4. OPERATION CYCLE

The operation phase of IC engine vehicle focuses on the vehicle's environmental impact during use. Fuel efficiency means assessment of energy consumption during operation (liters of fuel per kilometer). CO_2 emission during vehicle use occurs due to combustion of fuel inside the engine cylinders. The combustion of **diesel and petrol** inside the engine cylinders of conventional vehicles releases significant amounts of **carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM),** that contribute air pollution and climate change. During combustion, **petrol engines** use a spark ignition system, producing approximately **2.3 kg of CO_2 per liter** of fuel burned. In contrast, **diesel engines**, which rely on compression ignition, emit around **2.7 kg of CO_2 per liter** but are more fuel-efficient. However, diesel engines produce higher levels of **NO_x and soot**, leading to smog and respiratory issues. The combustion process inside the engine cylinders follows the chemical reaction i.e. **Fuel + Oxygen → CO_2 + H_2O + Heat + Pollutants.** Incomplete

combustion results in **carbon monoxide and unburned hydrocarbons,** further worsening air quality.

All sub-cycles and their various phases of electric vehicles (EV) are discussed below:

4.5.5. VEHICLE PRODUCTION CYCLE

This sub-cycle encompasses all activities from raw material extraction to vehicle assembly and end-of-life processing.

Material extraction: Mining of raw materials, refining and processing materials into usable forms like iron, aluminum, copper, plastics and rare-earth elements used for components such as the engine, body, transmission, electrical parts, other sub-assemblies, tyre, tube, flap rest and lubrication oils such as gear oil, brake fluid etc. Each of these items contributes to carbon emissions through extraction, refining, and manufacturing. Steel & Cast produces emissions from diesel-powered mining equipment, transportation, and high-temperature smelting in blast furnaces using coal-derived coke. Aluminum consumes high energy in refining bauxite to alumina and electrolysis in smelting leads to significant emissions, especially when powered by fossil fuels. Copper for mining, smelting, and refining processes require high energy inputs, often powered by coal or diesel that results CO_2 emission. Natural rubber production involves deforestation and processing with fossil fuel energy resulting carbon emission. Similarly synthetic rubber, derived from petroleum, emits CO_2 during refining and polymerization. Plastic derived from crude oil and natural gas, plastic production releases emissions during extraction, refining, and polymer manufacturing. Glass involves melting silica sand at high temperatures in furnaces powered by fossil fuels contributes to emissions. Lubrication oils produced from **e**xtracting, refining, and processing lubricants release CO_2 from fossil fuel combustion. Carbon Fiber is highly energy-intensive process leading to carbon emission; carbon fiber production emits CO_2 due to high-temperature processing and fossil fuel-based electricity use.

Material parts manufacturing: Producing individual vehicle parts like transmission, thermal system, controller, on board charger, charging port, power

converter, electric motor, axle, chassis, body and wheels, etc, other sub assemblies and consumables and combining all parts into a finished vehicle in manufacturing plants. These multiple processes generate carbon emissions due to energy-intensive operations and material consumption. Metal Cutting & machining processes like milling, turning, and drilling require CNC machines which are operated by electricity that generate carbon emissions. Coolants and lubricants used in machining add indirect emissions. Welding such as arc, laser, and resistance welding consume high electricity or gas (acetylene, CO_2), producing emissions from energy use and burning shielding gases. Grinding & polishing like abrasive grinding generates dust and heat, requiring electricity-powered equipment, contributing to emissions, especially when grid electricity relies on coal. Casting & forging produces melting metals in foundries and shaping them in forges require high-temperature furnaces, often powered by coal, oil, or gas, leading to significant CO_2 emissions. Stamping & pressing through hydraulic and mechanical presses use large amounts of electricity, while lubrication oils and metal treatments add to emissions. Plastic Molding & Composite Processing like injection molding and carbon fiber curing require high temperatures and fossil-fuel-based electricity, contributing to emissions. The use of fasteners, adhesives, and robotic assembly lines increases energy consumption that generates carbon emission. Final assembling of parts and testing involves operation of robotic machines, quality checks and functional testing that consumes electricity and compressed air emits CO_2. Painting & Coating such as Spray painting and electro-coating involve solvents and chemical curing, releasing volatile organic compound and energy-intensive drying ovens all of which involves release of carbon emissions.

Assembling: Final assembling of parts and testing involves robotic machines, quality checks, and functional testing that consumes electricity and compressed air etc., that indirectly emit CO_2. Painting & Coating such as Spray painting and electro-coating involve solvents and chemical curing, releasing volatile organic compounds and energy-intensive drying ovens all of which involves release of carbon emissions.

Transportation: Shifting materials and components between facilities by road, rail and ship etc. The transportation of automobile components and complete

vehicles generates carbon emissions from fossil fuel combustion in various modes of transport. Road transport like diesel-powered trucks transport sub assemblies like engines, transmissions, chassis, and cooling systems between suppliers and factories. It emits CO_2 depending on distance, load weight, and fuel efficiency. Rail is more fuel-efficient than road transport but still emits CO_2 from diesel-powered locomotives. Electrified rail systems also produce emissions through power generation and transmission. Global supply chains rely on heavy fuel oil-powered ships to transport large components like transmissions, hydraulics, and complete vehicles. These ships produce significant CO_2. Occasionally, urgent sub-parts like electronics, fuel systems, and specialized components are air-freighted, generating high CO_2 emissions per unit weight. Transporting lubricants, coolants, and fuel system components involves tanker trucks and ships, with emissions from both fuel combustion and evaporative losses.

Use/Maintenance: While electric vehicles have zero tailpipe emissions, their use and maintenance still contribute to carbon emissions, primarily through charging and energy conversion processes. Battery Charging & Discharging Losses as EV batteries are not 100% efficient; energy is lost as heat during charging and discharging cycles. These inefficiencies increase electricity demand and associated emissions. Power Conversion Systems Components like onboard chargers, inverters, and power electronics generate heat and experience energy losses, leading to indirect emissions from additional power generation. Regenerative braking helps improve efficiency; energy losses still occur in conversion and storage processes. Carbon Emissions from EV Maintenance include battery management & replacement. Over time, battery degradation requires energy-intensive diagnostics, repairs, or replacements, contributing to emissions from material production and transportation. EVs require coolant changes and lubrication for specific components, generating emissions from fluid production and disposal.

End-of-life/recycling: Processing and recycling materials from scrapped vehicles to recover metals, plastics, and other components. The end-of-life processing of automobiles generates carbon emissions from transportation, dismantling,

shredding, recycling, and reprocessing. Scrap vehicles are transported via diesel-powered trucks or rail to dismantling and recycling facilities, emitting CO_2 based on distance and load weight. Removing reusable parts (engines, batteries, fuel systems) and draining fluids (oil, coolant) requires energy for tools and handling, generating indirect emissions. Hydraulic shears and presses cut and compress vehicle bodies for easier transport and processing, consuming electricity or diesel-powered hydraulics, leading to CO_2 emissions. High-powered shredders break down metal and non-metal components, consuming large amounts of electricity, often derived from fossil fuels. Magnetic and eddy current separators sort materials, adding to energy use. Steel, aluminum, and copper are melted in electric arc or induction furnaces, consuming significant energy. Emissions depend on electricity sources and fuel use in smelting. Plastics may be incinerated, emitting CO_2, or reprocessed, requiring heat and chemicals. Tire recycling involves shredding, pyrolysis, or repurposing, each with varying energy demands. Non-recyclable materials decompose in landfills, releasing methane and CO_2. Incineration produces additional emissions.

4.5.6. POWER CYCLE

The power cycle for BEVs involves the fuel extraction, transportation, power production, transmission, charging/use of electricity by vehicle and reuse/disposal.

Fuel extraction: Fuel extraction is a major source of carbon emissions across different power generation methods. Coal mining, through surface or underground methods, releases methane (CH_4), a potent greenhouse gas. Various operations such as transportation, crushing, and processing of coal emits carbon dioxide emissions. Oil extraction, refining, and transportation contribute significantly to CO_2 emissions. Offshore drilling and tar sand extraction are particularly energy-intensive, leading to high carbon footprints. While cleaner than coal and oil, natural gas extraction through drilling and hydraulic fracturing results in methane leaks, which have a high global warming potential. Uranium mining and enrichment require substantial energy, mostly from fossil-fuel-powered machinery, resulting in indirect CO_2 emissions. However, the lifecycle emissions remain lower than fossil fuel-based power. Though fuel extraction is minimal,

reservoir construction can lead to methane emissions from decomposing organic matter in flooded areas. Mining of silicon, silver, and rare metals for photovoltaic cells has a moderate carbon footprint, mainly due to fossil-fuel-powered mining and processing. Turbine manufacturing requires metals like steel and rare earth elements, whose extraction emits CO_2. However, emissions are low compared to fossil fuels.

Transportation: Fuel transportation contributes significantly to carbon emissions across various power generation methods. Transporting coal from mines to power plants via trucks, trains, or ships consumes fossil fuels, releasing carbon dioxide and other pollutants. Long-distance shipping of coal, especially across countries, adds to its carbon footprint. Oil and refined petroleum products are transported through pipelines, tankers, and trucks, all of which rely on fossil fuels. Pipeline leaks and spills can also result in methane and volatile organic compound (VOC) emissions. Transporting natural gas via pipelines requires significant energy, often powered by gas compression stations that emit CO_2. Liquefied natural gas (LNG) transportation by ship involves energy-intensive cooling and re-gasification, further increasing emissions. Uranium ore and enriched fuel transportation via road, rail, or ship requires fossil fuel consumption, leading to indirect CO_2 emissions. However, nuclear fuel is transported less frequently due to its high energy density. Since water is the energy source, fuel transportation emissions are negligible. However, transporting materials for dam construction adds some emissions. Transportation emissions arise from moving raw materials (silicon, metals) and manufactured components (solar panels, wind turbines) to installation sites. Offshore wind farms require fuel-intensive shipping operations. Overall, fossil fuel-based power has the highest transportation-related emissions, whereas renewable and nuclear power have much lower transport-related carbon footprints.

Power production: Producing electricity from sources such as coal, natural gas, hydropower, solar, or wind. The energy source mix greatly influences the environmental footprint. Electricity production generates carbon emissions depending on the energy source and conversion efficiency. Burning coal

releases high levels of carbon dioxide, sulfur oxides, nitrogen oxides, and particulate matter. Coal combustion is the most carbon-intensive electricity source. Natural gas emits less CO_2 than coal but still contributes significantly to emissions. Combined cycle gas plants are more efficient, but methane leaks from extraction and transport increase climate impact. Oil-based power generation is less common but used in some regions, burning oil for electricity emits CO_2, NOx, and particulates, with higher emissions than natural gas but lower than coal. In hydro-power operational emissions are low, large reservoirs can release methane from decomposing organic matter. Construction and land-use changes also contribute to emissions. Solar panels have negligible emissions during operation, but manufacturing, transportation, and installation involve emissions from mining, refining, and energy-intensive production processes. Wind turbines produce no direct emissions, but manufacturing and installation require materials like steel and concrete, generating some CO_2 during production. Emits no direct CO_2, but uranium mining, refining, plant construction, and decommissioning have associated emissions.

Energy Transmission: Transmission electricity through grids to charging stations or home chargers, including associated energy losses. Transmission electricity through grids to charging stations or home chargers generates carbon emissions due to energy losses, infrastructure maintenance, and fossil-fuel-based electricity generation. Transmission and distribution (T&D) losses occur as electricity travels through high-voltage power lines, transformers, and local grids. These losses, typically 5–10%, increase the overall carbon footprint when sourced from fossil fuels. Building and maintaining power lines, transformers, and substations require energy-intensive materials like steel, aluminum, and concrete, contributing to indirect emissions. The emissions from electricity transport depend on the energy mix of the grid. If electricity is primarily from coal or natural gas, emissions are higher; renewable sources reduce the impact. Public charging stations consume additional energy for cooling, lighting, and operational electronics, increasing overall power demand and emissions. Electric vehicle (EV) batteries lose energy during charging due to heat

dissipation, typically 5–15%, indirectly increasing the electricity required and emissions.

Charging/use by vehicle: Charging the BEV's battery, with efficiency losses during charging and discharging. Charging a battery electric vehicle (BEV) generates carbon emissions depending on the electricity source and efficiency losses during charging and discharging. Charging emissions depend on the energy mix of the grid. Fossil fuel-based power (coal, natural gas) results in higher CO_2 emissions, while renewable energy (solar, wind) reduces the impact. Energy is lost as heat during charging, typically 5–15%, due to resistance in charging cables, connectors, and battery management systems, increasing electricity demand and emissions. Lithium-ion batteries experience energy losses during the conversion of AC grid electricity to DC storage, contributing to additional energy consumption. BEVs use cooling or heating systems to maintain battery temperature during charging, consuming extra energy and increasing emissions. Home chargers and public charging stations draw small amounts of electricity even when idle, adding to indirect emissions. Energy is lost during battery discharge and power delivery to the motor, reducing overall efficiency and indirectly increasing emissions per mile traveled.

Reuse/disposal: The end-of-life phase of power generation systems involves dismantling, recycling, and waste disposal, all of which contribute to carbon emissions. Decommissioning coal plants involves demolishing infrastructure, handling toxic coal ash, and reclaiming land, all of which require fossil-fuel-powered equipment. Coal ash disposal can release methane (CH_4) from landfills. Dismantling oil-fired plants emits CO_2 from heavy machinery. Used oil and sludge disposal can contribute to emissions if improperly handled. Some components can be recycled, but refining and transport add to the carbon footprint. Gas turbines and pipelines require dismantling and material recycling, which consumes energy and emits CO_2. Residual methane leaks from pipelines or storage tanks can also contribute to emissions. Decommissioning nuclear plants is energy-intensive, requiring specialized handling of radioactive materials. While spent fuel is stored or reprocessed, both processes have an indirect carbon footprint from transportation and shielding infrastructure. Dams

have long lifespan, but their decommissioning involves heavy equipment, leading to emissions. Reservoir drawdown can release methane from decomposed biomass. Recycling solar panels and wind turbine blades is challenging and energy-intensive. Some materials, like silicon and steel, can be recovered, but composite materials often end up in landfills, contributing to emissions from waste processing. Overall, fossil fuel-based plants have the highest end-of-life emissions, while renewable have lower but still notable impacts from material recycling and disposal.

4.5.7. BATTERY CYCLE

Material extraction: The extraction and processing of materials used in electric vehicle batteries, such as lithium, cobalt, nickel, and graphite, contribute significantly to carbon emissions. Mining operations involve energy-intensive activities, including drilling, blasting, transportation, and refining, primarily powered by fossil fuels. Lithium, essential for modern lithium-ion batteries, is mined from hard rock or extracted from brine. Hard rock mining requires extensive crushing and heating, generating high emissions. Brine extraction is less energy-intensive but consumes large amounts of water, indirectly contributing to environmental stress. Fossil fuel requirement for nickel and cobalt, used in high-performance batteries, also have high due to energy-intensive extraction and refining processes. In particular, laterite nickel mining requires smelting at high temperatures, often using coal-powered plants. Graphite, a key material in Li-ion battery anodes, has a significant carbon footprint due to its energy-intensive extraction and processing methods. The primary sources of carbon emissions in graphite production include mining operations**.** **N**atural graphite is extracted from open-pit or underground mines using heavy diesel-powered machinery for drilling, blasting, and transportation. These operations release substantial CO_2 emissions. Natural graphite ore undergoes crushing, grinding, flotation, and thermal or chemical purification. These processes require high energy inputs, often sourced from fossil fuels, contributing to greenhouse gas emissions. Synthetic graphite, derived from petroleum coke, involves graphitization at temperatures above 2500°C,

consuming large amounts of electricity, typically from coal or gas-powered grids, leading to high emissions.

Battery manufacturing: The production of Li-ion battery components for electric vehicles (EVs) involves several carbon-intensive processes due to the use of materials such as lithium, cobalt, nickel, graphite, and aluminum. The key sources of carbon emissions in parts production include cathode & anode manufacturing, cell assembly & battery pack manufacturing**,** Cathodes and anodes require chemical synthesis and high-temperature treatments, consuming large amounts of energy. The production of electrolytes and separators involves energy-intensive chemical processing, generating carbon emissions. Cell assembly & battery pack manufacturing includes giga-factories and battery plants consume large amounts of electricity for electrode coating, drying, and assembly. The energy source of these facilities significantly impacts emissions. Module & pack assembly means individual cells are integrated into modules and then assembled into battery packs with cooling systems, wiring, and casings. This process involves robotic automation and material processing, consuming additional energy resulting carbon emissions. Battery assembly plants require energy for climate control, clean room environments, and automation, contributing to emissions depending on the energy source used.

Transportation: The transportation and distribution of Li-ion battery materials, components, and assembled packs involve significant carbon emissions due to the global supply chain. Key sources of emissions include raw material transport, component and parts shipping, battery pack distribution, warehouse and logistics operations and last-mile delivery**.** Lithium, cobalt, nickel, and graphite are often mined in countries like Australia, Chile, and the Democratic Republic of Congo but refined elsewhere. The transportation of these raw materials via diesel-powered trucks, trains, and cargo ships generates substantial CO_2 emissions. After refinement, materials are processed into battery parts such as electrodes, electrolytes, and separators. These parts are then transported to giga-factories for battery assembly, often across continents, adding to emissions. Assembled battery packs are heavy and require specialized handling, increasing fuel consumption and emissions during transportation to

EV manufacturing plants. Air freight, though faster, has a particularly high carbon footprint. Storage and handling of battery materials in warehouses and logistics hubs consume electricity and fuel, depending on the energy mix used in these facilities. Delivering batteries to assembly plants and service centers involves additional emissions from trucks and rail networks.

Use by vehicle: The use phase of electric vehicles (EVs) with Li-ion batteries generates carbon emissions primarily through electricity consumption for charging. Fast-charging stations consume more electricity and often require grid upgrades, which may indirectly increase emissions if additional fossil fuel-based power generation is needed. Over time, battery efficiency declines, leading to increased charging frequency and higher overall electricity consumption, which can contribute to emissions depending on the energy source. Energy use during driving, including heating, cooling, and auxiliary systems, affects the vehicle's efficiency and the frequency of charging cycles, indirectly influencing emissions.

Recycling/Disposal: Recovering valuable materials like lithium and cobalt or safely disposing of end-of-life batteries. The recovery of valuable materials such as lithium, cobalt, and nickel from end-of-life vehicle batteries involves energy-intensive processes that contribute to carbon emissions. Recycling and safe disposal are essential to minimize environmental impact, but these processes themselves require substantial energy input. Mechanical recycling involves shredding batteries to separate metals, plastics, and active materials. This process consumes electricity and generates CO_2 emissions, especially if powered by fossil fuels. Pyro-metallurgical recycling uses high-temperature furnaces to extract metals like cobalt and nickel. This method is highly energy-intensive and emits significant amounts of CO_2 and other pollutants. Hydrometallurgical recycling dissolves battery materials in acid solutions to recover lithium, cobalt, and other metals. Although this method has lower emissions than smelting, it requires chemical processing and wastewater treatment, contributing to indirect carbon emissions. Direct recycling aims to refurbish battery components with minimal processing, offering the lowest emissions.

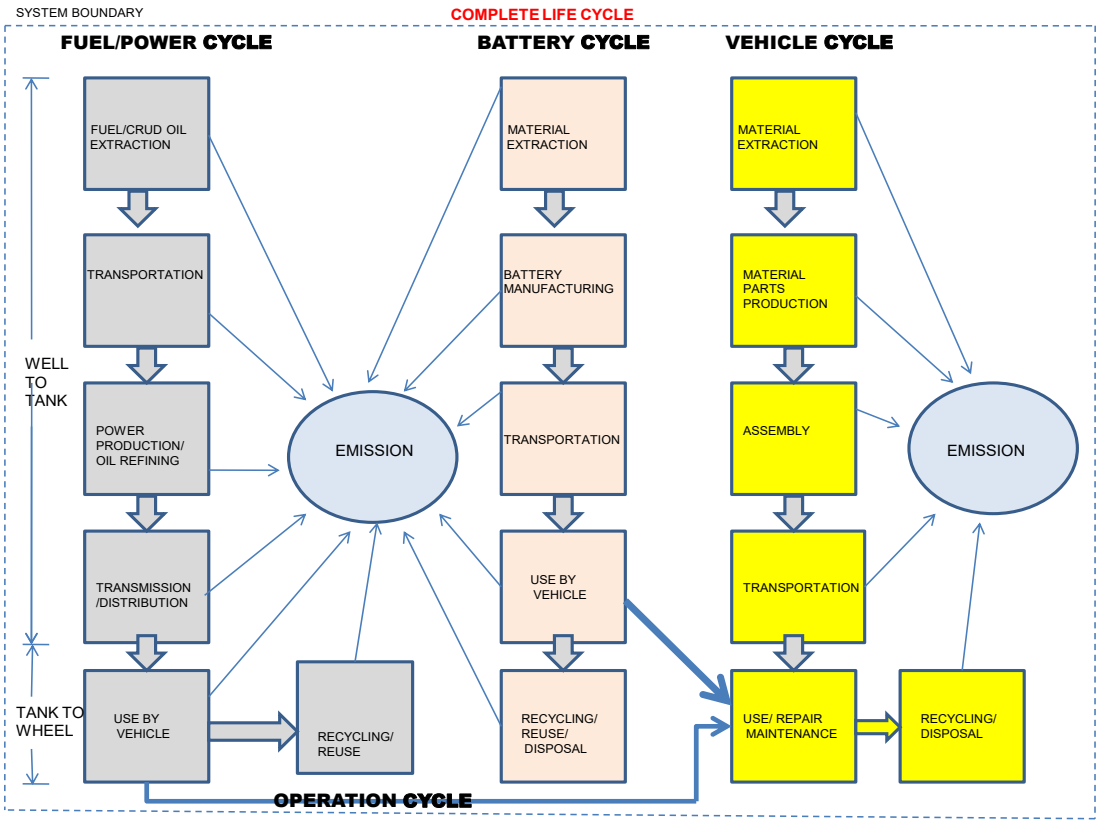
4.5.8. OPERATION CYCLE

The operation phase for BEVs focuses on the vehicle's environmental impact during use. While BEVs produce no tailpipe emissions, upstream emissions from electricity generation are considered. The transmission of electricity from the generation point to electric vehicle (EV) charging stations involves multiple stages—high-voltage transmission, transformation, distribution, and final delivery through EV chargers—each contributing to carbon emissions. Electricity losses occur at various stages. High-voltage transmission lines experience 2–6% energy loss due to resistance and heat dissipation. Transformers contribute to additional losses. Distribution networks lose 4–10% of electricity before reaching charging points. EV chargers also have efficiency losses, typically 5–10%, depending on charging speed and technology.

Figure 4.2 offers a thorough summary of all the emissions related to a vehicle's life cycle, including the fuel, battery, and vehicle cycles. The fuel cycle, which includes phases including transportation, refinement, power generation, and distribution, monitors emissions from the extraction of crude oil or fuel to its use in automobiles. It encompasses both downstream (tank-to-wheel) and upstream (well-to-tank) processes. The battery cycle examines how batteries affect the environment, starting with the extraction of basic minerals like cobalt and lithium and continuing through production, shipping, and emissions from power used for charging.

The vehicle cycle describes the emissions that occur during the manufacture, use, and disposal of automobiles. This covers the extraction of raw materials, the production of components, the assembly of vehicles, maintenance, and the recycling or disposal of end-of-life products. All of these phases are included in the system boundary, which provides a comprehensive picture of emissions from the raw material stage to vehicle use and final disposal. The graphic emphasises how crucial it is to evaluate a vehicle's environmental impact across its whole lifecycle, particularly when contrasting electric and traditional internal combustion engine vehicles.

Figure 4.2: Conceptual Model for Emission



Estimation Method

Vehicle production cycle: carbon emission from vehicle production cycle consists of three components i.e., carbon emission from material extraction and production, carbon emission from vehicle assembly and carbon emission during recycling and disposal. Carbon emission from material extraction and production is estimated by multiplying vehicle weight and carbon emission factor for material extraction and production. Carbon emission from vehicle assembly and transportation is estimated by multiplying vehicle weight and carbon emission factor for vehicle assembly and transportation. Similarly carbon emission from recycling and disposal is estimated by multiplying vehicle weight and carbon emission factor for recycling and disposal. Life time carbon emission from vehicle production cycle is estimated by summing up all three component of a vehicle i.e., carbon emission from material extraction and production, vehicle assembly and vehicle recycling and disposal. Finally life time emission from vehicle production cycle is estimated

by calculating average of emission from vehicle production cycle of all vehicles of a particular group like two wheeler or car considered for the study.

Fuel cycle: carbon emission from fuel cycle consists of five components i.e., crude extraction, refining process, crude transportation, oil distribution and recycling/reuse. Firstly the life time requirement of fuel consumption is estimated by multiplying fuel consumption for one Km distance covered and vehicle life in Km. Carbon emission from fuel cycle is estimated from the multiplication of life time requirement of fuel consumption of a vehicle and sum of carbon emission factor for crude extraction, carbon emission factor for refining process, carbon emission factor for crude transportation, carbon emission factor for oil distribution and carbon emission factor for recycling/reuse. Finally life time emission from fuel cycle is estimated by calculating average of emission from fuel cycle of all vehicles of a particular group like two wheelers or car considered for the study.

Battery cycle: carbon emission from battery cycle consists of five components i.e., material extraction, transportation, battery manufacturing, battery use and recycling/reuse. Carbon emission from battery cycle is estimated from the multiplication of battery capacity in KWH and sum of carbon emission factor for material extraction, carbon emission factor for transportation, carbon emission factor for battery manufacturing, carbon emission factor for battery use and carbon emission factor for recycling/reuse. Finally life time emission from battery cycle is estimated by calculating average of emission from battery cycle of all vehicles of a particular group like two wheeler or car considered for the study.

Power cycle: From research data it has been observed that power mix of present Indian power consists of 54.3% coal, 37.9% RE, 6.5% natural gas, 1.7% nuclear and 0.1% diesel. Firstly the life time requirement of power consumption is estimated with multiplication of power consumption for one Km distance covered by the vehicle and vehicle life in Km. Carbon emission factor for coal power is obtained from multiplication of percentage of power generation from coal and carbon emission factor of power from coal. Carbon emission factor for RE power is obtained from multiplication of percentage of power generation from RE and

carbon emission factor of power from RE. Carbon emission factor for nuclear power is obtained from multiplication of percentage of power generation from nuclear and carbon emission factor of power from nuclear. Carbon emission factor for natural gas power is obtained from multiplication of percentage of power generation from natural gas and carbon emission factor of power from natural gas. Carbon emission factor for diesel power is obtained from multiplication of percentage of power generation from diesel and carbon emission factor of power from diesel. Carbon emission from power cycle is estimated from the multiplication of life time requirement of power consumption of a vehicle and sum of carbon emission factor for material coal power, carbon emission factor for RE power, carbon emission factor for nuclear power, carbon emission factor for natural gas power and carbon emission factor for diesel power. Carbon emission from coal consists of five components i.e., material extraction, transportation, power generation, power distribution/transmission and reuse/disposal. Carbon emission factor from coal is estimated from the sum of carbon emission factor for material extraction, carbon emission factor for transportation, carbon emission factor for power generation, carbon emission factor for power distribution/transmission and carbon emission factor for reuse/disposal. Since the value of carbon emission factor for material extraction, transportation and reuse/disposal for RE power, nuclear power and natural gas power are very less and negligible; these factors are not considered here. Finally life time emission from power cycle is estimated by calculating average of emission from power cycle of all vehicles of a particular group like two wheelers or car considered for the study.

Finally life cycle carbon emission for IC engine vehicle is estimated by summing up Life time carbon emission from vehicle production cycle, Life time carbon emission from battery cycle, Life time carbon emission from fuel cycle and Life time carbon emission from operation cycle. Similarly life cycle carbon emission for electric vehicle is estimated by summing up Life time carbon emission from vehicle production cycle, Life time carbon emission from battery cycle, Life time carbon emission from power cycle and Life time carbon emission from operation cycle. Impact of EV adoption in terms of carbon

emission reduction has been estimated by deducting life time carbon emission of electric vehicle from life time carbon emission from IC engine vehicle.

Estimating Formula:

Vehicle Production Cycle:

$$CO_2\ emission\ from\ vehicle\ material\ extraction\ and\ parts\ production\ from\ each\ vehicle$$

$$(Vpm)\ in\ Kg\ = Vehicle\ weight\ (Kg) \times \sum (percentage\ of\ each\ material\ \times$$

$$carbon\ emission\ factor\ of\ the\ material\ extraction\ and\ parts\ production).$$

$$CO_2\ emission\ from\ vehicle\ assembly\ \&\ transportation\ (Vpa)\ in\ Kg = Vehicle\ weight\ (Kg) \times carbon\ emission\ factor\ for\ vehicle\ assembly\ \&\ transportation.$$

Here value of carbon emission factor for vehicle assembly & transportation is considered as 0.20 obtained from literature review

$$CO2\ emission\ during\ recycling\ and\ disposal\ (Vpr)\ in\ Kg = Vehicle\ weight\ (Kg) \times \sum (percentage\ of\ each\ material\ \times$$

$$carbon\ emission\ factor\ of\ the\ material\ recycling\ and\ disposal).$$

$$CO_2 emission from lifecycle vehicle production\ (VLce)\ in Kg = (\sum Vpm)/N\ +\ (\sum Vpa)/N\ + (\sum Vpr)/N$$

Where N is the number of vehicles considered

Fuel Cycle:

$$Requirement\ of\ fuel\ (diesel/petrol)\ for\ lifetime\ vehicle\ use\ in\ Ltr.\ (Fcu) = Fuel\ consumption\ per\ Km\ in\ Ltr\ \times\ Vehicle\ life\ in\ Km$$

$$CO_2 emission for fuel cycle\ (Fce)\ in Kg\ =\ Fcu\ \times \sum (carbon\ emission factor\ for\ crude\ extraction + carbon\ emission factor for\ refining\ process\ + carbon\ emission\ factor\ for\ crude\ oil\ transport\ +$$

$carbon\ emission\ factor\ for\ oil\ distribution\ +$
$carbon\ emission\ factor\ for\ recycling/reuse)$

$$CO_2 emission from fuel life cycle\ (FLce)\ in Kg\ =\ (\sum Fce)/N$$

Battery Cycle:

$$CO_2\ emission\ for\ battery\ production\ cycle\ (Bce) in\ Kg$$
$$=\ Battery\ capacity\ in\ KWH$$
$$\times \sum (carbon\ emission\ factor\ for\ battery\ material\ extraction$$
$$+\ carbon\ emission\ factor\ for\ battery\ manufacturing$$
$$+ carbon\ emission\ factor\ for\ transportation$$
$$+ carbon\ emission\ factor\ for\ battery\ use\ by\ vehicle$$
$$+\ carbon\ emission\ factor\ for\ battery\ recycling/disposal)$$

$$CO_2 emission from battery life cycle\ (BLce)\ in Kg\ =\ (\sum Bce)/N$$

Power Cycle:

$$Requirement\ of\ electricity\ (power)\ for\ lifetime\ vehicle\ use\ in\ KWH\ (Pcu)$$
$$=\ Electricity\ (power)\ consumption\ per\ Km\ in\ KWH$$
$$\times\ Vehicle\ life\ in\ Km$$

$$CO2\ emission\ for\ power\ cycle\ (Pce)\ in\ Kg$$
$$=\ Pcu\ \times\ carbon\ emission\ factor\ for\ life\ cycle\ power\ production$$

$$Carbon\ emission\ factor\ for\ life\ cycle\ power\ production$$
$$=\ \sum (percentage\ of\ power\ production\ from\ coal\ \times$$

$$carbon\ emission\ factor\ of\ power\ from\ coal\ in\ g\ CO2eq/KWH$$
$$+ percentage\ of\ power\ production\ from\ RE\ \times$$

$$carbon\ emission\ factor\ of\ power\ from\ RE\ in\ g\mathrm{CO_2}eq/KWH$$
$$+ percentage\ of\ power\ production\ from\ nuclear\ power\ \times$$

$$carbon\ emission\ factor\ of\ power\ from\ nuclear\ power\ in\ g\ CO2eq/KW$$
$$H+ percentage\ of\ power\ production\ from\ natural\ gas\ \times$$

$$carbon\ emission\ factor\ of\ power\ from\ natural\ gas\ in\ g\ CO2\ eq$$
$$/KWH\ )$$

$$Carbon\ emission\ factor\ of\ power\ from\ coal =$$
$$\sum (carbon\ emission\ factor\ for\ coal\ transportation +$$
$$carbon\ emission\ factor for\ power\ production\ +$$
$$carbon\ emission\ factor\ for\ power\ transmission\ +$$
$$carbon\ emission\ factor\ for\ power\ use\ by\ vehicle\ +$$
$$carbon\ emission\ factor\ for\ recycling/disposal)$$

Indian Power Mix: (Coal 54.3%, RE 37.9%, Natural gas 6.5%, nuclear power 1.7% and Diesel 0.1%)

Operation Cycle:

For IC engine vehicle

$CO2\ emission\ for\ Operation\ cycle\ (Oceic)\ in\ Kg$ = *Fuel consumption per unit distance X Life time distance cover X emission factor for unit quantity fuel combustion*

$$CO2\ emissionfromoperationlifecycle\ (OLceic)\ inKg\ =\ (\sum Oceic)/N$$

For Electric Vehicle:

$CO2\ emission\ for\ Operation\ cycle\ (Oceev) in\ Kg$
$= Electricity\ consumption\ per\ unit\ distance\ X\ Life\ time\ distance\ cover\ X$

$$emission\ factor\ for\ unit\ quantity\ power\ generation$$

$$CO2\ emission\ from\ operation\ life\ cycle\ (OLceev)\ in\ Kg$$
$$=\ (\sum Oceev)/N$$

$$Lifetime\ CO2\ emission\ for\ ICE\ vehicle\ in\ Kg$$
$$=\ V_{Lce} +\ B_{Lce} +\ F_{Lce}\ +\ OLceic$$

$$Lifetime\ CO2\ emission\ for\ BEV\ vehicle\ in\ Kg$$
$$=\ V_Lce +\ B_Lce +\ P_Lce +\ OLceev$$

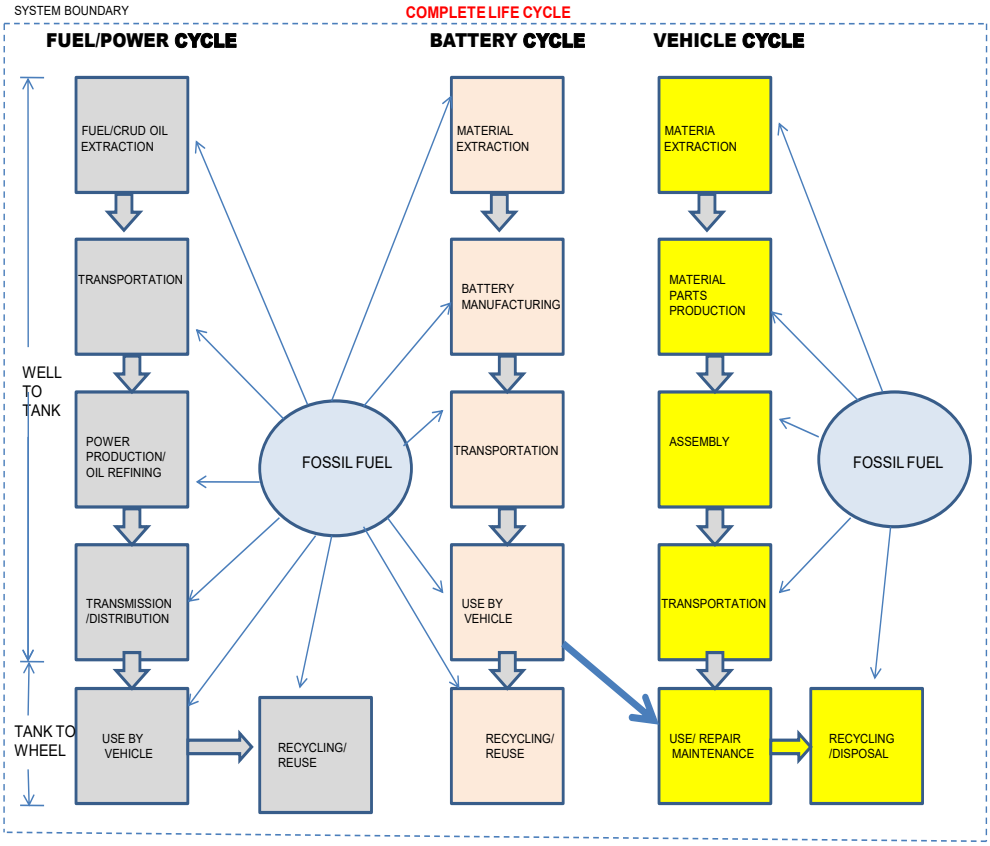
4.6. METHODOLOGY FOR RESEARCH OBJECTIVE-III

Theoretical framework

To assess the impacts of EV adoption in Indian automotive sector in terms of fossil fuel requirement. The Comparative Life Cycle Assessment approach has

been used in this case also. Life Cycle Assessment is a methodology for assessing environmental impacts associated with all the stages (manufacturing, use and end to life) of the life cycle of a product, process or service. A questionnaire survey has been conducted among the driver/user of related EV and ICE vehicles. The data related to usage has been gathered based on survey methods and balance data has been gathered from secondary sources like research articles, journals, govt and private web site. The responses are analyzed using the LCA model concept. Necessary calculations have been carried out with the help of MS excel.

Figure 4.3: Conceptual Model for Fossil Fuel



Research Objective –III of this study is "Impact of EV adoption in terms of fossil fuel consumption in Maharashtra". To achieve this research objective, comparative life cycle assessment concept has been used. Functional unit considered for life time distance covered by a vehicle in Km. Four types of vehicle considered here i.e., two wheelers, three wheelers, car and bus. Life of two wheelers both IC engine and electric vehicle are considered as 90,000 Km.

Life of three wheelers both IC engine and electric vehicle are considered as 288,000 Km. Similarly, life of car both IC engine and electric vehicle are considered as 150,000 Km. Life of bus both IC engine and electric vehicle are considered as 720,000 Km. Various types of fossil fuels used for all types vehicles is considered are diesel, petrol, natural gas and coal. Functional unit of coal is considered in Kg whereas functional unit of diesel and petrol is considered as litre. Functional unit of natural gas is considered in cubic meter. Fossil fuel consumption occurred in complete life cycle of IC engine vehicle and electric vehicle have been assessed separately and then total fossil fuel consumption by both type of vehicles are compared. Accordingly net fossil fuel consumption due to adoption of electric vehicle is assessed. Fossil fuel consumption component of each type of vehicle are described in succeeding paragraphs.

A Life Cycle Assessment evaluates the environmental impacts associated with all stages of a vehicle's life, from raw material extraction to disposal or recycling. For an Internal Combustion Engine (IC) vehicle, the LCA can be divided into several sub-cycles: Vehicle Cycle, Fuel Cycle, Battery Cycle, and Operation Cycle. Vehicle cycle consists of various stages such as raw material extraction/mining, part manufacturing, assembling, vehicle production, use/maintenance and end of life. Battery cycle consists of raw material extraction/mining, transportation, battery manufacturing, charging/power consumption, use by vehicle and disposal/recycling/reuse etc. Fuel cycle consists of fuel/crud extraction, transportation, oil refining, oil distribution, use by vehicle and recycling/reuse etc. Operation cycle consists of use/maintenance of vehicle production, battery use by vehicle and fuel use by vehicle etc.

A Life Cycle Assessment (LCA) for a Battery Electric Vehicle (BEV) also evaluates the environmental impacts associated with all stages of a vehicle's life, from raw material extraction to disposal or recycling. The LCA of a BEV can be divided into key sub-cycles: Vehicle Cycle, Power Cycle, Battery Cycle, and Operation Cycle, with detailed processes within each sub-cycle. Vehicle cycle consists of various stages such as raw material extraction/mining, part manufacturing, assembling, vehicle production, use/maintenance and end of

life. Battery cycle consists of raw material extraction/mining, transportation, battery manufacturing, charging/power consumption, use by vehicle and disposal/recycling/reuse etc. Power cycle consists of fuel/ extraction, transportation, power generation, power distribution, and use by vehicle etc. Operation cycle consists of use/maintenance of vehicle production, battery use by vehicle and fuel use by vehicle etc.

The life cycle fuel consumption of a vehicle has been estimated considering sum of fossil fuel consumption during its entire lifespan, from raw material extraction to end-of-life disposal. To comprehensively assess the environmental impact of conventional internal combustion engine vehicles (ICEVs) and electric vehicles (EVs), it is necessary to break down their life cycle into distinct sub-cycles, including the vehicle cycle, fuel cycle/power cycle, battery cycle, and operation cycle. Each of these sub-cycles consists of multiple stages have been explained in previous paragraphs. A systematic understanding of these stages provides a holistic view of fuel consumption associated with both vehicle types.

All sub-cycles and their various phases of conventional internal combustion engine vehicles (ICEVs) are discussed below:

Vehicle Production Cycle

This sub-cycle encompasses all activities from raw material extraction to vehicle assembly and end-of-life processing.

Material extraction: Mining of raw materials, refining and processing materials into usable forms like iron, aluminum, copper, plastics and rare-earth elements used for components such as the engine, body, transmission, electrical parts, other sub assemblies, tyre, tube, flap rest and lubrication oils such as engine oil, gear oil, brake fluid etc. Each of these items required fossil fuel consumption for extraction, refining, and manufacturing. Diesel-powered mining equipments, transportation, and high-temperature smelting in blast furnaces used for production of **s**teel & cast iron that emits carbon dioxide**.** Aluminum consumes high energy in refining bauxite to alumina and electrolysis in smelting leads to significant fossil fuel consumption, especially for fossil fuel

powered prime mover. Copper for mining, smelting, and refining processes require high energy inputs, often powered by coal or diesel. Natural rubber production involves deforestation and processing with fossil fuel energy. Similarly synthetic rubber, derived from petroleum. Plastic derived from crude oil and natural gas, plastic production consumes fossil fuel consumption during extraction, refining, and polymer manufacturing. Glass involves melting silica sand at high temperatures in furnaces powered by fossil fuels. Lubrication oils produced from **e**xtracting, refining, and processing lubricants during fuel combustion. Carbon Fiber is highly energy-intensive process and carbon fiber production requires fossil fuel consumption due to high-temperature processing and fossil fuel-based electricity use.

Part/Component manufacturing: Producing individual vehicle parts like the engine assembly, clutch, transmission system, brake system, other sub assemblies and consumables and combining all parts into a finished vehicle in manufacturing plants. These multiple processes require fuel due to energy-intensive operations and material consumption. Metal cutting & machining processes like milling, turning, and drilling require CNC machines which are operated by electricity that consume fuel. Coolants and lubricants used in machining add fuel consumption. Welding such as arc, laser, and resistance welding consume high electricity or gas, resulting energy use. Grinding & polishing like abrasive grinding generates dust and heat, requiring electricity-powered equipment requires fuel, especially when grid electricity relies on coal/oil. Casting & forging produces melting metals in foundries and shaping them in forges require high-temperature furnaces, often powered by coal, oil, or gas, leading to significant fuel consumption. Stamping & pressing through hydraulic and mechanical presses use large amounts of electricity. Plastic Molding & Composite Processing like injection molding and carbon fiber curing require high temperatures and fossil-fuel-based electricity.

Assembling of parts: Electricity and compressed air required for **f**inal assembling of parts**,** quality checking and functional testing done through robotic machines emits carbon dioxide. Painting & Coating such as Spray painting and electro-coating involve solvents and chemical curing, releasing

volatile organic compounds and energy-intensive drying ovens all of which involves requirement of fuels.

Transportation: Shifting materials and components between facilities by road, rail and ship etc. Fossil fuel is the essential requirement for the transportation of automobile components and complete vehicles need fossil fuel combustion in various modes of transport. Road transport like diesel-powered trucks transport sub assemblies like engines, transmissions, chassis, and cooling systems between suppliers and factories also require fuel, depending on distance, load weight, and fuel efficiency. Rail is more fuel-efficient than road transport but still need fossil fuel for electricity generation and transmission. Global supply chains rely on heavy fuel oil-powered ships to transport large components like transmissions, hydraulics, and complete vehicles. Occasionally, urgent sub-parts like electronics, fuel systems, and specialized components are air-freighted, requiring high quantity air fuel per unit weight. Transporting lubricants, coolants, and fuel system components involves tanker trucks and ships, with fuel requirement for both fuel combustion and evaporative losses.

Use/Maintenance: During maintenance, processes such as engine tuning, oil changes, and fuel system cleaning need energy which ultimately comes from fossil fuel. Repair activities involving welding, painting, or part replacements may also require fuel. Additionally, energy consumption in service centers, disposal of used engine oil, and improper handling of worn-out components contribute to consumption of fossil fuel.

End-of-life/recycling: Processing and recycling materials from scrapped vehicles to recover metals, plastics, and other components. The end-of-life processing of automobiles require fossil fuel for transportation, dismantling, shredding, recycling, and reprocessing. Scrap vehicles are transported via diesel-powered trucks or rail to dismantling and recycling facilities. Removing reusable parts (engines, batteries, fuel systems) and draining fluids (oil, coolant) requires energy for tools and handling. Hydraulic shears and presses cut and compress vehicle bodies for easier transport and processing, consuming electricity or diesel-powered hydraulics. High-powered shredders break down metal and non-metal components, consuming large amounts of electricity, often derived from fossil

fuels. Magnetic and eddy current separators sort materials, adding to energy use. Steel, aluminum, and copper are melted in electric arc or induction furnaces, consuming significant energy. Consumption of fossil fuel depends on electricity sources and fuel use in smelting. Plastics may be incinerated or reprocessed, requiring heat and chemicals that ultimately require fossil fuel. Tire recycling involves shredding, pyrolysis, or repurposing, each with varying energy demands.

Fuel Cycle

This sub-cycle evaluates the environmental impact of fuel production, distribution, and consumption.

Crude Extraction: Drilling and mining for crude oil require fuel consumption at multiple stages, including extraction, processing, and transportation. **Exploration & site preparation** such as seismic surveys, land clearing, and road construction require diesel-powered equipment and offshore drilling rigs that consume large amounts of fuel for operations. Oil drilling rigs, whether onshore or offshore, use diesel generators and machinery for drilling, pumping, and well maintenance. Enhanced oil recovery methods, such as gas injection, further increase fuel consumption. Extracting oil from tar sands or shale requires energy-intensive processes like steam-assisted gravity drainage or hydraulic fracturing, consuming fossil fuels. Pipelines, tankers, and trucks transport crude oil from extraction sites to refineries, need fuel for combustion in these transport systems. Handling produced water, drilling muds, and waste gases involves additional energy use.

Transportation: The transportation such as marine transportation, pipeline operations of crude oil from offshore oil rigs to refineries is a significant source of fuel consumption**.** Crude oil is often transported via tankers, which burn fossil fuels such as heavy fuel oil or marine diesel. The combustion of these fuels releases. Pipelines are another major mode of crude oil transportation. While they are more energy-efficient than tankers, they still require electricity or gas-powered pumps to maintain pressure and flow, leading to fuel consumption, especially if the electricity is generated from fossil fuels.

Oil refining: Refining crude oil into gasoline or diesel and producing additives. Refining crude oil into gasoline, diesel, and additives needs some amount of fuel through energy-intensive processes and chemical transformations. Refineries heat crude oil in distillation columns use fossil fuel-powered furnaces. Cracking & reforming processes like fluid catalytic cracking and hydro-cracking break down heavy hydrocarbons into lighter fuels, require high temperatures and hydrogen. Removing sulfur from diesel and gasoline uses hydrogen, generated via steam methane reforming (SMR). Additives like ethanol, detergents, and octane boosters require energy-intensive chemical processing. Refineries operate large compressors, pumps, and cooling systems, relying on fossil fuel-based electricity and steam. Waste & byproduct handling processing residues, such as coke and sulfur, requires further handling and energy use.

Oil distribution: Delivering refined fuel to distribution centers and fueling stations need some amount of fuel through transportation, storage, and handling. Pipelines, the primary method for transporting gasoline and diesel, use electric or gas-powered pumps to move fuel over long distances, consume fuel depending on energy sources. Fuel is transported from refineries or terminals to gas stations using diesel-powered tanker trucks. Fuel consumption varies based on distance, load weight, and fuel efficiency. Diesel-powered trains transport large fuel quantities to regional distribution hubs, require some portion of fuel for locomotive fuel combustion. Large tankers move refined fuel across oceans, burning heavy fuel oil. Fuel station pumps use electricity, often sourced from fossil fuels during dispensing.

Fuel Combustion: The engine operation is carried out by burning fuel. The internal combustion engine use gasoline and diesel that are primarily fossil fuels. Processes like Idling, stop-and-go traffic, and inefficient acceleration increase fuel consumption. Internal combustion engines waste energy as heat, reducing fuel efficiency and increasing fuel consumption per unit of useful energy. Catalytic converters and diesel particulate filters (DPFs) require additional energy.

Recycle/reuse: The end-of-life phase of fossil fuels like diesel, petrol, and lubricants in internal combustion engine (ICE) vehicles use a significant quantity of fossil fuel. Re-refining and reusing lubricants involve energy-intensive processes that need fuel. Waste oil recycling and fuel reclamation require transportation, processing, and chemical treatments, all of which lead to fuel consumption. Some recycling methods, such as distillation and re-blending, consume substantial energy, increasing their fuel consumption. Disposal of residual fuels and lubricants contributes to fuel consumption.

Battery Cycle

Material extraction: Although IC engine vehicles rely minimally on batteries (e.g., for starting, lighting, and ignition), assessing their lifecycle is critical. The extraction and processing of materials used in conventional vehicle batteries, such as lead, lithium, and nickel, need a good amount of fossil fuel. Mining operations involve energy-intensive activities, including drilling, blasting, transportation, and refining, primarily powered by fossil fuels. Lead, commonly used in lead-acid batteries, is extracted through underground or open-pit mining. The smelting and refining process also need energy that comes from fossil fuel. Lithium, essential for modern lithium-ion batteries, is mined from hard rock or extracted from brine. Hard rock mining requires extensive crushing and heating that require fuel. Brine extraction is less energy-intensive but still it consumes fuel. Nickel and cobalt, used in high-performance batteries, are produced through energy-intensive extraction and refining. In particular, laterite nickel mining requires smelting at high temperatures, often using coal-powered plants.

Battery parts manufacturing: The manufacturing of lead-acid batteries, commonly used in internal combustion engine (ICE) vehicles, involves substantial use of fossil fuels throughout various stages of production. Key components of lead-acid batteries include lead plates, sulfuric acid electrolyte, and plastic casings—each of which depends on fossil fuel energy for raw material extraction, processing, and assembly. Lead mining and smelting are energy-intensive processes that often rely on diesel-powered machinery and fossil fuel-based electricity. The refining of lead and the casting of battery plates involve high-temperature operations typically powered by coal or natural gas.

Sulfuric acid, another major component, is produced through chemical processes that also consume significant energy, often sourced from fossil fuels. The plastic used in battery casings is usually made from petroleum-derived materials like polypropylene. Manufacturing these casings involves fossil fuel use both as raw material and as energy source for molding and shaping.

Battery Assembly: Assembling lead-acid batteries for internal combustion engine (ICE) vehicles involves multiple processes that depend significantly on fossil fuel energy, either directly or indirectly. While the battery components—such as lead plates, sulfuric acid, and plastic casings—are manufactured separately, their assembly into a functional unit involves energy-intensive operations often powered by fossil-fueled electricity, especially in regions where renewable energy penetration is low. The assembly process includes pasting lead oxide onto grids, curing and drying plates, stacking electrodes, inserting separators, and placing them into plastic containers. These steps require controlled heating, mechanical handling, and precision machinery—typically operated with electricity generated from fossil fuels like coal or natural gas. In some cases, diesel generators may also be used, especially in regions with unreliable power supply. The acid-filling, battery sealing, and initial charging (formation process) are particularly energy-intensive. The formation process involves applying electric current to the assembled battery to convert lead oxide into active material, which consumes substantial energy—often from fossil fuel-based grids. Thus, fossil fuels play a critical role in powering the machinery and systems used in lead-acid battery assembly for ICE vehicles.

Transportation/distribution: The transportation of battery materials, components, and fully assembled lead-acid batteries for internal combustion engine (ICE) vehicles heavily relies on fossil fuels at every stage of the supply chain. Raw materials such as lead ore, sulfur, and petroleum-based products used for plastic casings are extracted from mines and oil fields, then transported—often over long distances—using diesel-powered trucks, trains, and cargo ships. Once processed, these materials are delivered to various manufacturing plants. For example, lead is shipped to smelters and refineries, sulfur to chemical plants for sulfuric acid production, and polymers to molding

units for battery casings. Each of these transport steps typically involves fossil fuel-based logistics systems, primarily trucks and freight carriers running on diesel or petrol. After the individual battery components are manufactured, they are transported to assembly plants. Again, this involves multiple freight movements, often spanning regional or international boundaries. The final assembled lead-acid batteries are then distributed to vehicle manufacturers, dealerships, or aftermarket retailers using similar fossil fuel-dependent transportation networks. Additionally, battery recycling and disposal also require fossil-fueled transportation to and from collection and reprocessing facilities. Thus, from raw material extraction to final delivery, fossil fuels play an essential role in the entire transportation lifecycle of lead-acid batteries.

Charging/ use by vehicle: The use and charging of lead-acid batteries in internal combustion engine (ICE) vehicles are indirectly linked to fossil fuel consumption. These batteries primarily serve to start the engine and power electrical systems when the engine is off. Once the engine is running, the vehicle's alternator recharges the battery using mechanical energy derived from the engine itself, which operates on fossil fuels such as petrol or diesel. Since the alternator is driven by the engine, the energy used for battery charging ultimately comes from the combustion of fossil fuels. This means every time the battery is recharged during vehicle operation, a portion of the fuel burned contributes to replenishing the battery's charge. In addition to in-vehicle charging, lead-acid batteries may also be charged externally, particularly during manufacturing, testing, or when recharging a discharged battery. In such cases, electricity is drawn from the grid, which in many regions is still heavily powered by fossil fuels like coal, natural gas, or oil. Moreover, fossil fuels power the logistics and maintenance systems supporting battery operation—such as service tools, charging stations, and diagnostic equipment—especially in traditional garages. Thus, both direct and indirect fossil fuel consumption is integral to the use and charging of lead-acid batteries in ICE vehicles.

Battery Recycling/Disposal: The reuse, recycling, and disposal of lead-acid batteries used in internal combustion engine (ICE) vehicles involve several stages that rely heavily on fossil fuels. While lead-acid batteries are among the

most recycled consumer products globally, the processes involved are energy-intensive and depend on fossil fuel-based systems. Collection and transportation of used batteries to recycling facilities are typically carried out using diesel-powered trucks and other fossil-fueled vehicles. At recycling plants, fossil fuels are used either directly for thermal processes or indirectly through fossil fuel-based electricity. For example, smelting—the process of recovering lead from used batteries—requires high-temperature furnaces, often powered by coal, natural gas, or oil. Separating the battery components, such as lead, plastic, and acid, also involves mechanical and chemical processes that consume significant energy, commonly supplied by grids dominated by fossil fuel generation. The recovered plastic is usually re-melted and remolded using heat from fossil-fueled sources, while sulfuric acid is either neutralized or converted to other chemicals, often requiring energy inputs. Even in the disposal of non-recyclable materials, fossil fuels are used for transport and landfill operations. Thus, despite the environmental benefits of battery recycling, the entire reuse and disposal lifecycle of lead-acid batteries remains closely tied to fossil fuel consumption.

Operation Cycle

The operation phase of IC engine vehicle focuses on the vehicle's impact on fossil fuel during use. Fuel efficiency means assessment of energy consumption during operation (liters of fuel per kilometer). The combustion of **diesel and petrol** inside the engine cylinders of conventional vehicle consume significant amounts of fuel consumption**.** Internal combustion engine (ICE) operation relies heavily on fossil fuels, primarily petrol and diesel, to generate power. These fuels are burned within the engine's cylinders to create controlled explosions, converting chemical energy into mechanical energy that drives the vehicle. Additionally, engine components like fuel pumps, injectors, and exhaust systems are designed specifically for fossil fuel use. The efficiency and performance of ICE vehicles are directly tied to the quality and availability of fossil fuels, making their operation a continuous source of fossil fuel consumption.

Electric vehicle (EV) operation, while free of tailpipe emissions, still involves fossil fuel use indirectly. The electricity used to charge EVs often comes from

power plants that burn fossil fuels like coal, natural gas, or oil, especially in regions with carbon-intensive energy grids. Charging infrastructure and grid maintenance also rely on fossil-fuel-powered logistics and machinery. Additionally, energy losses during transmission and distribution further increase the overall fossil fuel input. Therefore, although EVs are more energy-efficient and environmentally friendly compared to internal combustion engine vehicles, their operation still contributes to fossil fuel consumption depending on the electricity generation mix. The transmission of electricity from the generation point to electric vehicle (EV) charging stations involves multiple stages—high-voltage transmission, transformation, distribution, and final delivery through EV chargers—each add fuel consumption indirectly. Electricity losses occur at various stages. High-voltage transmission lines (from power plants to substations) experience 2–6% energy loss due to resistance and heat dissipation. Transformers contribute to additional losses. Distribution networks lose 4–10% of electricity before reaching charging points. EV chargers also have efficiency losses, typically 5–10%, depending on charging speed and technology.

All sub-cycles and their various phases of electric vehicles (EV) are discussed below:

Vehicle Production Cycle

This sub-cycle encompasses all activities from raw material extraction to vehicle assembly and end-of-life processing.

Material extraction: Mining of raw materials, refining and processing materials into usable forms like iron, aluminum, copper, plastics and rare-earth elements used for components such as the engine, body, transmission, electrical parts, other sub assemblies, tyre, tube, flap rest and lubrication oils such as gear oil, brake fluid etc. The extraction and mining of above materials used in electric vehicle (EV) production—such as steel, cast iron, aluminum, copper, rubber, glass, composite materials, plastics, grease, and lubricants—rely heavily on fossil fuels. Diesel-powered machinery is widely used in mining operations, while fossil-fuel-based energy powers crushing, smelting, and refining

processes. Steel and aluminum production require high-temperature furnaces typically fueled by coal or natural gas. Rubber and plastics are derived from petroleum. Transport of raw materials and finished parts also uses fossil-fueled logistics. Lubricants and greases are petroleum-based products. Thus, fossil fuels play a crucial role across the entire material supply chain for EV manufacturing.

Part/Component manufacturing: Producing individual electric vehicle (EV) parts—such as the transmission, thermal system, controller, onboard charger, charging port, power converter, electric motor, axle, chassis, body, wheels, and other sub-assemblies—requires energy-intensive manufacturing processes powered largely by fossil fuels. Machining, molding, casting, and assembling components often use electricity from fossil-fuel-based grids, along with diesel-powered equipment for material handling. Consumables like adhesives, coolants, and paints are petroleum-derived. In manufacturing plants, assembling all components into a finished vehicle involves automation, robotics, and HVAC systems, often powered by fossil fuel-derived electricity or backup generators. Stamping & pressing through hydraulic and mechanical presses use large amounts of electricity, while lubrication oils and metal treatments add fuel consumption. Plastic Molding & Composite Processing like injection molding and carbon fiber curing require high temperatures and fossil-fuel-based electricity. The use of fasteners, adhesives, and robotic assembly lines increases energy consumption. Assembling of parts, final assembling of parts and testing involves robotic machines, quality checks, and functional testing that consumes electricity and compressed air. Painting & Coating such as Spray painting and electro-coating involve solvents and chemical curing and energy-intensive drying ovens all of which consumes fuel.

Assembly: In the assembly of different components and sub-assemblies—such as motors, power electronics, chassis, and body panels—traditional manufacturing relies heavily on energy from fossil fuels. For instance, forging, casting, and welding processes consume large amounts of energy, often derived from coal or natural gas, particularly in countries with carbon-intensive grids. Even within the final assembly plants, various operations like painting, drying,

and equipment operation utilize fossil-fuel-based energy unless the facility has transitioned to renewable. Thus, while EVs help reduce tailpipe emissions, their production process remains carbon-intensive due to dependence on fossil fuels across the supply chain and manufacturing stages.

Transportation: Shifting materials and components between facilities by road, rail and ship etc. The transportation of automobile components and complete vehicles need fossil fuel in various modes of transport. Road transport like diesel-powered trucks transport sub assemblies like engines, transmissions, chassis, and cooling systems between suppliers and factories. It consumes fuel depending on distance, load weight, and fuel efficiency. Rail is more fuel-efficient than road transport from diesel-powered locomotives. Electrified rail systems also produce emissions through power generation and transmission. Global supply chains rely on heavy fuel oil-powered ships to transport large components like transmissions, hydraulics, and complete vehicles. These ships consume significant amount of fuel. Occasionally, urgent sub-parts like electronics, fuel systems, and specialized components are air-freighted, ultimately using fossil fuel. Transporting lubricants, coolants, and fuel system components involves tanker trucks and ships, with fuel consumption.

Use/Maintenance: Battery charging & discharging losses is an important parameter as EV batteries are not 100% efficient; energy is lost as heat during charging and discharging cycles. These inefficiencies increase electricity demand. Power conversion systems components like onboard chargers, inverters, and power electronics that generate heat and experience energy losses, leading additional power generation. Regenerative braking helps improve efficiency; energy losses still occur in conversion and storage processes. While electric vehicles are known for their reduced operational dependence on fossil fuels compared to internal combustion engine vehicles, their repair and maintenance processes may still involve indirect fossil fuel consumption. Many maintenance activities, such as transportation of spare parts, operation of service facilities, and manufacturing of replacement components, rely on fossil fuel-powered systems. For instance, logistics vehicles that deliver EV parts often run on diesel or petrol. Additionally, the machinery and equipment used in service

centers, including lifts, compressors, and diagnostic tools, are often powered by electricity that, in many regions like Maharashtra, is still partially generated from fossil fuels. Therefore, while EVs significantly reduce direct fossil fuel consumption, their repair and maintenance chain still involves fossil fuel use, especially in regions where renewable energy adoption is limited.

End-of-life/recycling: The reuse, recycling, and end-of-life processes of electric vehicles (EVs) and their components also involve fossil fuel consumption, primarily due to the energy-intensive nature of these activities and the current reliance on conventional energy sources. Dismantling of EVs, transportation of components to recycling facilities, and operation of heavy machinery often depend on diesel or petrol-powered vehicles and equipment. In regions like Maharashtra, where a significant portion of electricity is generated from fossil fuels, the energy used in recycling processes indirectly contributes to carbon emissions. While EVs offer long-term environmental benefits, their end-of-life phase currently relies on infrastructures and systems that are not yet fully sustainable. Removing reusable parts and draining fluids (oil, coolant) requires energy for tools and handling. Hydraulic shears and presses cut and compress vehicle bodies for easier transport and processing, consuming electricity or diesel-powered hydraulics. High-powered shredders break down metal and non-metal components, consuming large amounts of electricity, often derived from fossil fuels. Magnetic and eddy current separators sort materials, adding to energy use. Steel, aluminum, and copper are melted in electric arc or induction furnaces, consuming significant energy. Emissions depend on electricity sources and fuel use in smelting. Plastics may be incinerated or reprocessed, requiring heat and chemicals. Tire recycling involves shredding, pyrolysis, or repurposing, each with varying energy demands.

Power cycle

The power cycle for BEVs involves the fuel extraction, transportation, power generation, transmission, charging/use of electricity by vehicle and reuse/disposal.

Fuel extraction: Fuel extraction requires fossil fuel directly or indirectly across different power generation methods. Coal power plants need fuel for coal mining, whether through surface or underground methods. Transportation, crushing, and processing of coal also requires further fuel consumption. Oil-fired power also needs fuel for oil extraction, refining, and transportation. Offshore drilling and tar sand extraction are particularly energy-intensive. Natural Gas Power **is** cleaner than coal and oil, natural gas extraction through drilling and hydraulic fracturing results feeding of fossil fuels. Nuclear power also need for uranium mining and enrichment require substantial energy, mostly from fossil-fuel-powered machinery, resulting in indirect CO_2 emissions. For h**y**dropower**,** though fuel extraction is minimal, reservoir construction requires fuels. Solar Power need mining of silicon, silver, and rare metals for photovoltaic cells has a moderate requirement of fuels due to fossil-fuel-powered mining and processing. Wind Power also needs fuel for turbine manufacturing that requires metals like steel and rare earth elements,

Transportation: Fuel transportation needs fuel across various power generation methods. Coal Power Plants requires transporting coal from mines to power plants via trucks, trains, or ships that consumes fossil fuels. Long-distance shipping of coal, especially across countries, adds to its fuel requirements. For o**i**l-fired power**,** crude oil and refined petroleum products are transported through pipelines, tankers, and trucks, all of which rely on fossil fuels. Natural gas power needs transportation of natural gas via pipelines which requires significant amount of energy, often powered by gas compression stations run by fossil fuel based energy source. Liquefied natural gas transportation by ship involves energy-intensive cooling and re-gasification, further increasing fuel requirement. Nuclear power needs uranium ore and enriched fuel transportation via road, rail, or ship which requires fossil fuel consumption. For h**y**dropower, water is the energy source; however, transporting materials for dam construction need fuel. Solar and wind power transportation need fossil fuel for moving raw materials (silicon, metals) and manufactured components (solar panels, wind turbines) to installation sites. Offshore wind farms require fuel-intensive shipping operations.

Power production: Fossil fuel usage varies significantly across different types of power plants, particularly during the electricity generation phase. Coal-fired power plants are among one of the most fossil fuel consuming power source, directly burning coal to produce steam for electricity. Oil-fired plants operate similarly, burning petroleum-based fuels, and are often used for peak or backup power due to high operational costs and emissions. Gas-fired plants, especially combined-cycle ones, are more efficient but still burn natural gas. In contrast, nuclear power plants do not burn fossil fuels during operation. Instead, they use nuclear fission to generate heat, producing virtually no greenhouse gas emissions during electricity generation. However, they may rely on fossil fuels indirectly for backup systems or during fuel processing. Hydropower plants generate electricity by harnessing flowing water, requiring no fossil fuels during operation. Similarly, solar and wind power produce electricity without consuming fossil fuels during generation. However, intermittent generation may necessitate backup from fossil fuel-based grids, especially in regions with limited energy storage. Overall, coal, oil, and gas plants depend heavily on fossil fuels for power production, while nuclear, hydro, solar, and wind provide cleaner alternatives with minimal to no fossil fuel use during their operational phases.

Energy Transmission: Transporting electricity through grids to charging stations or home chargers, including associated energy losses. Transporting electricity through grids to charging stations or home chargers needs additional fuel due to energy losses, infrastructure maintenance, and fossil-fuel-based electricity generation. Transmission and distribution (T&D) losses occur as electricity travels through high-voltage power lines, transformers, and local grids. These losses, typically 5–10%, increase the overall fuel consumption when sourced from fossil fuels. Building and maintaining power lines, transformers, and substations require energy-intensive materials like steel, aluminum, and concrete. The fuel requirements for electricity transport depend on the energy mix of the grid. If electricity is primarily from coal or natural gas, fossil fuel consumptions are higher; renewable sources reduce the impact. Public charging stations consume additional energy for cooling, lighting, and

operational electronics, increasing overall power demand. Electric vehicle (EV) batteries lose energy during charging due to heat dissipation, typically 5–15%, indirectly increasing the electricity required.

Charging/use of electricity by EV: The use of fossil fuels in lithium-ion (Li-ion) battery-powered electric vehicles (EVs) occurs primarily in two areas: battery production and electricity generation for charging. The mining, processing, and manufacturing of Li-ion batteries require significant energy, often sourced from fossil fuels like coal, oil, and natural gas, especially in countries with carbon-intensive energy grids. Additionally, EV charging indirectly consumes fossil fuels if the electricity comes from non-renewable sources. In regions where coal or natural gas dominate power generation, EVs rely on fossil fuels for operation, reducing but not eliminating greenhouse gas emissions compared to conventional internal combustion engine vehicles. In regions with a high dependency on coal and natural gas for electricity generation, fossil fuel consumptions can be significant. Charging emissions depend on the energy mix of the grid. Fossil fuel-based power (coal, natural gas) results in higher CO_2 emissions, while renewable energy (solar, wind) reduces the impact. Energy is lost as heat during charging, typically 5–15%, due to resistance in charging cables, connectors, and battery management systems, increasing electricity demand. Lithium-ion batteries experience energy losses during the conversion of AC grid electricity to DC storage, contributing to additional energy consumption. BEVs use cooling or heating systems to maintain battery temperature during charging, consuming extra. Home chargers and public charging stations draw small amounts of electricity even when idle, adding to indirect fuel consumption. Energy is lost during battery discharge and power delivery to the motor, reducing overall efficiency and indirectly increasing fuel consumption per mile traveled.

Reuse/disposal: The end-of-life phase of power generation systems involves dismantling, recycling, and waste disposal, all of which needs energy vis-à-vis fuel consumption. Coal power plants while decommissioning coal plants involves demolishing infrastructure, handling toxic coal ash, and reclaiming land, all of which require fossil-fuel-powered equipment. Oil-fired power

during dismantling oil-fired plants needs fuel for heavy machinery. Used oil and sludge disposal also need fuel if improperly handled. Some components can be recycled, but refining and transport add to the energy requirement. Natural gas power uses gas turbines and pipelines which require dismantling and material recycling and thus consumes energy. Decommissioning nuclear plants is energy-intensive process, requiring specialized handling of radioactive materials. While spent fuel is stored or reprocessed, both processes have an impact on fossil fuel consumption for transportation and shielding infrastructure. Hydropower dams have long lifespan, but their decommissioning involves heavy equipment, leading to fuel consumption. Solar and wind power involves solar panels and wind turbine blades recycling which is challenging and energy-intensive. Some materials, like silicon and steel, can be recovered, but composite materials often end up in landfills, resulting additional fuel consumption from waste processing. Overall, fossil fuel-based plants have the highest amount of fuel consumption while renewable have lower but still notable impacts from material recycling and disposal.

Battery Cycle

Material extraction: The extraction and processing of materials used in electric vehicle batteries, such as lithium, cobalt, nickel, and graphite, impact significantly to fuel consumptions. Mining operations involve energy-intensive activities, including drilling, blasting, transportation, and refining, primarily powered by fossil fuels. Lithium, essential for modern lithium-ion batteries, is mined from hard rock or extracted from brine. Hard rock mining requires extensive crushing and heating, requires energy. Brine extraction is less energy-intensive but consumes large amounts of water, indirectly contributing to energy requirement. Nickel and cobalt used in high-performance batteries, also have high fuel consumption due to energy-intensive extraction and refining. In particular, laterite nickel mining requires smelting at high temperatures, often using coal-powered plants. Graphite, a key material in Li-ion battery anodes, has a significant impact on fuel requirement due to its energy-intensive extraction and processing methods. The primary need of energy requirement in graphite production include mining operations**.** **N**atural graphite is extracted

from open-pit or underground mines using heavy diesel-powered machinery for drilling, blasting, and transportation. These operations need substantial amount of fuel. Natural graphite ore undergoes crushing, grinding, flotation, and thermal or chemical purification. These processes require high energy inputs. Synthetic graphite, derived from petroleum coke, involves graphitization at temperatures above 2500°C, consuming large amounts of electricity, typically from coal or gas-powered grids.

Battery Assembly: Producing battery material and battery cells and packs, including processes such as electrode coating and cell assembly. This stage has high energy demands. Electrode production involves mixing active materials (lithium, cobalt, nickel, manganese, graphite) with binders and solvents, followed by coating, drying, and calendaring. The drying process is highly energy-intensive, especially in facilities that rely on fossil-fuel-powered electricity. Cell assembly includes stacking or winding electrodes, adding separators and electrolytes, and sealing cells. This requires clean room environments with controlled temperature and humidity, increasing energy consumption. Formation and testing involve charging and discharging cycles to stabilize battery chemistry. This step alone needs prolonged electricity use. Battery pack assembly, where individual cells are integrated into modules and thermal management systems, further adds fuel consumption through material processing and transportation.

Transportation/distribution: The transportation and distribution of Li-ion batteries for electric vehicles (EV) require a good amount of fuel. The production of these batteries involves multiple stages, including raw material extraction, manufacturing, and distribution, all of which require extensive transportation networks. Lithium, Cobalt, Manganese, copper, aluminum, graphite, and other raw materials used in battery production are typically mined in one location, processed in another, and then transported to battery manufacturing facilities. This supply chain involves heavy machinery, trucks, ships, and trains, all of which consume fossil fuels. Once the batteries are manufactured, they are distributed to vehicle manufacturers, dealers, and service centers, further adding to the fuel consumption. The logistics of battery

recycling and disposal also contribute to emissions, as used batteries must be collected and transported to recycling facilities, often across long distances. Reducing the carbon emissions associated with Li-ion battery transportation requires optimizing supply chain logistics, using energy-efficient transportation methods, and promoting localized production.

Charging/ use by vehicle: The use of fossil fuels in lithium-ion (Li-ion) battery-powered electric vehicles (EVs) occurs primarily in two areas: battery production and electricity generation for charging. The mining, processing, and manufacturing of Li-ion batteries require significant energy, often sourced from fossil fuels like coal, oil, and natural gas, especially in countries with carbon-intensive energy grids. Additionally, EV charging indirectly consumes fossil fuels if the electricity comes from non-renewable sources. In regions where coal or natural gas dominate power generation, EVs rely on fossil fuels for operation, reducing but not eliminating greenhouse gas emissions compared to conventional internal combustion engine vehicles. In regions with a high dependency on coal and natural gas for electricity generation, these emissions can be significant.

Battery Recycling/Disposal: Recovering valuable materials like lithium and cobalt or safely disposing of end-of-life batteries. The recovery of valuable materials such as lithium, cobalt, and nickel from end-of-life vehicle batteries involves an energy-intensive process that comes from fossil fuel consumption. Recycling and safe disposal are essential to minimize environmental impact, but these processes themselves require substantial energy input. Mechanical recycling involves shredding batteries to separate metals, plastics, and active materials. This process consumes electricity and thus consumes fossil fuels. The reuse, recycling, and disposal of lithium-ion (Li-ion) batteries from electric vehicles (EVs) also involve fossil fuel use. These processes require energy for transportation, dismantling, and material recovery, often sourced from fossil-fuel-powered grids or vehicles. High-temperature treatments in recycling facilities, such as smelting, typically rely on coal or natural gas. Mechanical and chemical recycling methods also consume fossil-derived electricity and chemicals. Thus, despite reducing waste, battery recycling and disposal still

contribute to fossil fuel consumption depending on the energy mix and logistics employed.

Estimation Method:

Vehicle production cycle: Energy required for vehicle production is estimated by multiplying weight of vehicle and energy required for unit weight vehicle. Energy required for unit weight vehicle is factor calculated by summing up unit weight of each material extraction, part manufacturing, assembly, repair/maintenance and recycling/disposal. Value of energy required for unit weight vehicle has been obtained secondary sources. From the literature survey is found that energy requirement for material extraction and production, transportation and repair/maintenance cover 68% of total energy required. Energy required for part manufacturing cover 19% of total energy and vehicle assembly and disposal cover 13% of total energy. Material extraction and production, transportation and repair/maintenance is done by construction equipment operated with diesel as fuel, where as part manufacturing and vehicle assembly are done by machinery operated by electricity. Indian energy mix consists of 54.3% from coal, 37.9% from RE, 6.5% from natural gas, 1.7% from nuclear and 0.1% from diesel. Fossil fuel required producing power from coal, gas and diesel. Requirement of fossil fuel to produce nuclear power and RE power is very less and thus not considered. Diesel requirement for material extraction and production, transportation and repair/maintenance is estimated by multiplying energy requirement for material extraction and production, transportation & repair/maintenance and diesel required to generate one unit power. Value of diesel required to generate one unit power has been obtained from secondary data. Fossil fuels such as coal and natural gas are required for part manufacturing and vehicle assembly. Coal power requirement for part manufacturing and vehicle assembly are estimated by multiplying sum of power requirement for part manufacturing and vehicle assembly and 0.543 (as coal power covers 54.3% in Indian power mix). Coal requirement for part manufacturing and vehicle assembly are estimated by multiplying Coal power requirement for part manufacturing and vehicle assembly and 0.402 (as one KWH coal power consumes 0.402 kg coal). Actual coal requirement for part

manufacturing and vehicle assembly are estimated by multiplying another factor 1.1014 to compensate extra coal required for well to tank (WTT) such as fuel extraction, transportation etc. Gas power requirement for part manufacturing and vehicle assembly are estimated by multiplying sum of power requirement for part manufacturing and vehicle assembly and 0.0.065 (as gas power covers 6.5% in Indian power mix). Natural gas requirement for part manufacturing and vehicle assembly are estimated by multiplying gas power requirement for part manufacturing and vehicle assembly and 0.0.15 (as one KWH gas power consumes 0.15 CuM natural gas). WTT requirement for natural gas is not considered here due to very low value. Finally life time fossil fuel requirement from vehicle production cycle is estimated by calculating average of fossil fuel requirement from vehicle production cycle of all vehicles of a particular group like two wheeler or car considered for the study.

Fuel cycle: Life time requirement of fuel is estimated by multiplying fuel requirement for one Km and vehicle life in Km. For diesel engine vehicles, life time requirement of diesel is estimated by multiplying diesel requirement for one Km and vehicle life in Km. Actual diesel requirement is estimated by multiplying with another factor valued 2.25 to compensate WTT requirement. Similarly for petrol engine vehicles, life time requirement of petrol is estimated by multiplying petrol requirement for one Km and vehicle life in Km. Actual petrol requirement is estimated by multiplying with another factor valued 2.387 to compensate WTT requirement. Finally life time diesel requirement from fuel cycle is estimated by calculating average of diesel requirement from fuel cycle of all vehicles of a particular group like two wheelers or car considered for the study. Life time petrol requirement from fuel cycle is estimated by calculating average of petrol requirement from fuel cycle of all vehicles of a particular group like two wheelers or car considered for the study.

Battery cycle: Electricity requirement for battery cycle is obtained by multiplying battery KWH and energy factor for battery cycle of one KWH capacity. Fossil fuels like coal, diesel, and natural gas are required to generate electricity. Coal power part electricity for battery cycle is estimated by multiplying electricity requirement and a factor valued 0.543. Requirement of

coal for coal power is calculated with multiplication of three factors i.e, coal power part electricity for battery cycle, coal consumption factor for one KWH power valued as 0.402 and a WTT factor valued 1.1014. Gas power part electricity for battery cycle is estimated by multiplying electricity requirement and a factor valued 0.065. Requirement of natural gas for gas power is calculated with multiplication of two factors i.e, gas power part electricity for battery cycle and gas consumption factor for one KWH power valued as 0.15. Oil power part electricity for battery cycle is estimated by multiplying electricity requirement and a factor valued 0.001. Requirement of diesel for oil power is calculated with multiplication of two factors i.e, oil power part electricity for battery cycle and diesel consumption factor for one KWH power valued as 0.4. Finally life time coal requirement for battery cycle is estimated by calculating average of coal requirement of battery cycle of all vehicles of a particular group like two wheelers or car considered for the study. Life time natural gas requirement for battery cycle is estimated by calculating average of natural gas requirement of battery cycle of all vehicles of a particular group like two wheelers or car considered for the study. Life time diesel requirement for battery cycle is estimated by calculating average of diesel requirement of battery cycle of all vehicles of a particular group like two wheelers or car considered for the study.

Power cycle: Electricity requirement for power cycle of an electric vehicle is obtained by multiplying electricity consumption per Km in KWH and energy factor for battery cycle of one KWH capacity. Fossil fuels like coal, diesel, and natural gas are required to generate electricity. Coal power part electricity for power cycle is estimated by multiplying electricity requirement and a factor valued 0.543. Requirement of coal for coal power is calculated with multiplication of three factors i.e, coal power part electricity for power cycle, coal consumption factor for one KWH power valued as 0.402 and a WTT factor valued 1.1014. Gas power part electricity for power cycle is estimated by multiplying electricity requirement and a factor valued 0.065. Requirement of natural gas for gas power is calculated with multiplication of two factors i.e, gas power part electricity for power cycle and gas consumption factor for one KWH power valued as 0.15. Oil

power part electricity for power cycle is estimated by multiplying electricity requirement and a factor valued 0.001. Requirement of diesel for oil power is calculated with multiplication of two factors i.e, oil power part electricity for power cycle and diesel consumption factor for one KWH power valued as 0.4. Finally life time coal requirement for power cycle is estimated by calculating average of coal requirement of power cycle of all vehicles of a particular group like two wheelers or car considered for the study. Life time natural gas requirement for power cycle is estimated by calculating average of natural gas requirement of power cycle of all vehicles of a particular group like two wheelers or car considered for the study. Life time diesel requirement for power cycle is estimated by calculating average of diesel requirement of power cycle of all vehicles of a particular group like two wheelers or car considered for the study.

Finally life cycle coal requirement for IC engine vehicle is estimated by summing up life time coal required for vehicle production cycle and life time coal required for battery cycle. Similarly life cycle coal for electric vehicle is estimated by summing up life time coal required for vehicle production cycle, life time coal required for battery cycle and life time coal required for power cycle. Life cycle natural gas requirement for IC engine vehicle is estimated by summing up life time natural gas requirement for vehicle production cycle and life time natural gas requirement for battery cycle. Similarly life cycle natural gas requirement for electric vehicle is estimated by summing up life time natural gas requirement for vehicle production cycle, life time natural gas requirement for battery cycle and life time natural gas requirement for power cycle. Life cycle diesel requirement for IC engine vehicle is estimated by summing up life time diesel requirement for vehicle production cycle, life time diesel requirement for battery cycle and life time diesel requirement for fuel cycle. Similarly life cycle diesel requirement for electric vehicle is estimated by summing up life time diesel requirement for vehicle production cycle, life time diesel requirement for battery cycle and life time diesel requirement for power cycle. Life cycle petrol requirement for IC engine vehicle is same as life time petrol requirement for vehicle production cycle. Impact of EV adoption in terms of fossil fuel consumption has been estimated by deducting life time various

types of fossil fuels required for electric vehicle from life time similar types of fossil fuels required for IC engine vehicle.

Estimation formula:

Vehicle Production Cycle

$$Weight\ of\ vehicle\ =\ Wv\ Kg$$

$$Life\ cycle\ energy\ requirement\ of\ per\ Kg\ vehicle\ production = Evpk\ KWH/Kg$$

$$Life\ cycle\ energy\ requirement\ for\ vehicle\ production\ Evp = Wv\ \times\ Evpk\ KHW$$

$Life\ cycle\ energy\ requirement\ of\ per\ Kg\ vehicle\ production =$
(Energy requirement factor for material extraction + energy requirement factor for parts production + energy requirement factor for assembly + energy requirement factor for transportation + energy requirement factor for use/repair & maintenance + energy requirement factor for recycling/disposal)

Distribution

$Energy\ requirement\ for\ material\ extraction\ and\ material\ production\ (Emmp)$
$= Evp\ \times\ 0.68\ KWH$

$$Energy\ requirement\ for\ part\ production\ and\ transportation\ (Epp) = Evp\ \times\ 0.19\ KWH$$

$$Energy\ requirement\ for\ vehicle\ assembly\ and\ disposal\ (Eva) = Evp\ \times\ 0.13\ KWH$$

Material extraction and material production is done by construction equipment operated with diesel as fuel, whereas part production and vehicle assembly are done by machinery operated by electricity.

$Diesel\ required\ for$ Material extraction $and\ material\ production\ (Dmmp)$
$= Emmp\ \times\ 0.4\ ltr$

$$Coal\ required\ for\ part\ production, transportation, vehicle\ assembly$$

$$and\ disposal\ (Cppva)\ in\ Kg$$
$$= (Epp + Eva) \times 0.543 \times 0.402 + (Epp + Eva) \times 0.543\ X\ 0.402 \times 0.1014$$

$$Natural\ gas\ required\ for\ part\ production, transportation, vehicle\ assembly\ and\ disposal$$

$$(NGppva)\ in\ CuM = (Epp + Eva) \times 0.0.065 \times 0.15$$

$$Diesel\ required\ for\ part\ production, transportation, vehicle\ assembly\ and\ disposal$$

$$(Dppva)\ in\ ltr = (Epp + Eva) \times 0.001\ X\ 0.4$$

Life cycle fossil fuel requirement from vehicle production cycle

$$Coal\ (CLcfv) = (\sum Cppva)/N$$

$$Natural\ gas\ (NGLcfv) = (\sum NGppva)/N$$

$$Diesel\ (DLcfv) = (\sum Dppva)/N$$

Fuel Cycle

$$Requirement\ of\ fuel\ (Fr)$$
$$= Fuel\ consumption\ per\ Km\ in\ ltr \times Vehicle\ life\ in\ Km$$

$$Requirement\ of\ diesel\ (Dr)\ for\ diesel\ engine\ vehicle$$
$$= Diesel\ consumption\ per\ Km\ in\ ltr \times Vehicle\ life\ in\ Km$$

$$Requirement\ of\ petrol\ (Pr)\ for\ petrol\ engine\ vehicle$$
$$= Petrol\ consumption\ per\ Km\ in\ ltr \times Vehicle\ life\ in\ Km$$

$$Considering\ WTT\ requirement\ of\ diesel\ of\ 1.25\ KWH$$
$$/Ltr, additional\ energy\ requirement = Dr \times 1.25\ KWH$$

$$Additional\ requirement\ of\ diesel\ due\ to\ WTT\ (Dra)$$
$$= Dr \times 1.25\ X\ 0.4\ Ltr$$

$$Total\ diesel\ requirement\ (Dtf) = Dr + Dra$$

$$= Dr + Dr \times 1.25 \times 0.4\ Ltr$$

$$= Dr\ (1 + 1.25\ \times 0.4)\ Ltr$$

$$Considering\ WTT\ requirement\ of\ petrol\ of\ 1.387\ KWH\ /Ltr, additional\ energy\ requirement$$
$$= Pr\ \times\ 1.387\ KWH$$

$$Additional\ requirement\ of\ Petrol\ due\ to\ WTT\ (Pra)$$
$$= Pr\ \times\ 1.387\ \times\ 0.4\ Ltr$$

$$Total\ petrol\ requirement\ (Ptf)\ =\ Pr\ +\ Pra$$

$$= Pr\ +\ Pr\ \times\ 1.25\ 387 \times\ 0.4\ Ltr$$

$$= Pr(1 + 1.387 \times 0.4)\ Ltr$$

Life cycle fossil fuel requirement from fuel cycle

Petrol ($P_{L}cff$) = ($\sum Ptf$)/N

Diesel ($D_{L}cff$) = ($\sum Dtf$)/N

Power Cycle

$$Electricity\ (power)\ requirement\ (Ept)$$
$$= Electricity\ consumption\ per\ Km\ in\ KWH$$
$$\times\ Life\ of\ Veh\ in\ Km$$

$$Electricity\ part\ from\ Coal\ (Epc)\ =\ Ept\ \times\ 0.543\ KWH$$

$$Total\ coal\ requirement\ (Fpc)$$
$$= Epc\ \times\ 0.402 +\ Epc\ \times\ 0.402 \times\ 0.1014\ Kg$$

$$Electricity\ part\ from\ Natural\ gas\ (Epg)\ =\ Ept\ \times\ 0.065\ KWH$$

$$Natural\ gas\ requirement\ (Fpg)\ =\ Epg\ \times\ 0.15\ CuM$$

$$Electricity\ part\ from\ Diesel\ (Epd)\ =\ Ept\ \times\ 0.001\ KWH$$

$$Diesel\ requirement\ (Fpd)\ =\ Epd\ \times\ 0.4\ Ltr$$

Life cycle fossil fuel requirement from Power cycle

$$Coal\ (CLcfp)\ =\ (\sum Fpc)/N$$

$$Natural\ gas\ (NGLcfp)\ =\ (\sum Fpg)/N$$

$$Diesel\ (DLcfp)\ =\ (\sum Fpd)/N$$

Battery Cycle

$$Life\ cycle\ electricity\ requirement\ (Ebt)$$
$$=\ Battery\ KHW$$
$$\times\ Life\ cycle\ energy\ required\ to\ manufacture\ one\ KWH\ battery$$

Electricity only produced from coal, natural gas and diesel required fossil fuels.

$$Electricity\ part\ from\ coal\ (Ebc)\ =\ Ebt\ \times\ 0.543\ KWH$$

$$Coal\ requirement\ (Fbc)=\ Ebc\ X\ 0.402 +\ Ebc\ \times 0.402\ X\ 0.1014\ Kg$$

(0.1014 is WTT factor for coal)

$$Electricity\ part\ from\ natural\ gas\ (Ebg)\ =\ Ebt\ \times\ 0.0.065\ KWH$$

$$Natural\ gas\ requirement\ (Fbg)\ =\ Ebg\ \times\ 0.15\ CuM$$

$$Electricity\ part\ from\ diesel\ (Ebd)\ =\ Ebt\ \times\ 0.001\ KWH$$

$$Diesel\ requirement\ (Fbd)\ =\ Ebd\ \times\ 0.4\ Ltr$$

$$Life\ cycle\ fossil\ fuel\ requirement\ from\ Battery\ cycle$$

$$Coal\ (CLcfb)\ =\ (\sum Fbc)/N$$

$$Natural\ gas\ (NGLcfb)\ =\ (\sum Fbg)/N$$

$$Diesel\ (DLcfb)\ =\ (\sum Fbd)/N$$

Lifetime fossil fuel requirement for ICE vehicle

$$Coal\ =\ CLcfv$$

$$Natural\ gas\ =\ NGLcfv$$

$$Diesel\ =\ DLcfv +\ DLcff$$

$$Petrol\ =\ PLcff$$

Lifetime fossil fuel requirement for BEV vehicle

$$Coal = CLcfv + CLcfp + CLcfb$$

$$Natural\ gas = NGLcfv + NGLcfp + NGLcfb$$

$$Diesel = DLcfv + DLcfp + + DLcfb$$

The data in the table provides a detailed comparison of emissions and resource usage across different vehicle types (Two-Wheeler, Three-Wheeler, Car, Bus) and fuel sources (Petrol, Diesel, Coal, Natural Gas), differentiating between Internal Combustion Engine (ICE) vehicles and Battery Electric Vehicles (BEVs).

4.7. SAMPLING METHOD

Non-probability convenient sampling technique is used due to low population of EV user and for ease of data gathering.

4.8. SCOPE

The proposed study has been conducted on every type of IC engine driven vehicle and electric powered vehicle sector like two -wheeler, three-wheeler, car and bus etc. All types of electrically powered vehicles are considered due to a smaller number of availabilities of these types of vehicles in India. The geographical location has been covered the complete Maharashtra state in India.

4.9. DATA COLLECTION

The current study gathers data from both ***primary data sources*** *and* ***secondary data sources***. The study has employed the primary data collection method to collect data through a survey method using questionnaires. The secondary data has been collected from research papers, newspapers, magazines, government reports, company production and sales reports, government reports, government policies, automotive manufacturer association reports, survey reports etc.

A questionnaire survey has been conducted among the driver/user in Maharashtra, India of related EV and ICE vehicles. The combined questionnaire survey conducted was for both RO-II and RO-III. Survey was carried out in

various places of Maharashtra such as Nagpur, Nasik, Mumbai, Sholapur, Pune, Kolhapur, Beed, Amravati, Wardha, Aurangabad, Ahmednagar, Satara, Palghar and Jalgaon etc. Total 752 vehicle user has been surveyed and out of 752, only 682 accurate responses were accepted. 682 respondents from all segments were accepted. 70 forms have been rejected due to incomplete response. Segment wise details are given below:

Internal combustion engine two-wheel vehicles: Total 128 respondents form was accepted in this segment. Various make and model vehicles which includes Splendor, Shine, Victor, Passion pro, Deluxe, CT 100, Activa, CD 100, Apache, Platina, I Smart, Avenger, Pulsar, FZ, Unicorn, Xtrime, Jupiter, Discover, Gixxer, Aviator, XL 100 and CD dawn etc. of different manufacturer such as Hero, Honda, TVS, Bajaj, Yamaha, Suzuki etc. were surveyed. Both diesel and petrol engine vehicles are included here. Average annual usage of the vehicle is 6000 KM. Mileage of these vehicles found 35 to 80 KM per Litre. The ex-showroom price of these vehicles was found to be Rs 39478 to Rs 147569. Registration and other taxes found Rs 3029 to Rs 17733. Misc expenses reached Rs 927 to Rs 3552. Yearly insurance premiums reached Rs 1059 to Rs 2617. Average annual repair/maintenance cost found to be Rs 3438.

Battery Electric two-wheel vehicles: Total 74 respondents form was accepted in this segment. Various make and model vehicles which includes Revolt, Chetak, EV10, EV20, EV30, Optimac, Jetter, Zooba, Iqubes, TunwalTithino 20, Praise, Classic, NYX HX, Sharq, Dual, DIO, NEO, Joy, Nanu, 450X, Emerge, Storie, S1X, Okaya Fast F4, Ampere Maghus, Egale 100, Vantic, Okinawa Lite, Fasst F2T, Ridge 100, Kite Energy, Magnum X, Optima CX etc. of different manufacturer such as Hero, Honda, TVS, Bajaj, Okinawa, Ele Go, Emic India etc. were surveyed. Average annual usage of the vehicle is 6000 KM. The mileage of these vehicles was found to be 2.3 to 7.1 KWH per 100 KM. Ex-showroom price of these vehicles was found to be Rs 42850 to Rs 161748. Yearly insurance premiums reached Rs 600 to Rs 2617. The average annual repair/maintenance cost is found to be Rs 500.

Internal combustion engine three-wheel vehicles: Total 133 respondents form was accepted in this segment. Different manufacturer auto rickshaw and loader

were surveyed which includes Mahindra, Bajaj, Piaggio, TVS, Atul, Baxy, Lohia and Euler etc. Both diesel and petrol engine vehicles are included here. Average annual usage of the vehicle is 19,200 KM. Mileage of these vehicles found 19 to 40 KM per Litre. Ex-showroom price of these vehicles was Rs 185000 to Rs 394000. Average registration and other taxes were found to be Rs 17600. Average yearly insurance premium found Rs 1320. The average annual repair/maintenance cost is found to be Rs 6000.

Battery Electric three-wheel vehicles: Total 40 respondents form was accepted in this segment. Various make and model vehicles which includes JSA Ultra, Zorawar max, Altantis, Gem prince pro, Bajaj compact RE, Zezza super, TREO SFT, Rizin, Eride, Sutlez ZX, Piaggio Ape E city, Udaan EEVE and Mini metro etc. of different manufacturer such as Metro, Bajaj, Mahindra, Piaggio, Zorawar, Atlantis, JSA, Terra motor and A N motor etc. were surveyed. Average annual usage of the vehicle is 19,200 KM. Mileage of these vehicles found to be 3.28 to 4 KWH per 100 KM. Ex-showroom price of these vehicles found Rs 117000 to Rs 333000. Yearly insurance premiums were Rs 600 to Rs 1600. The average annual repair/maintenance cost is found to be Rs 3500.

Internal combustion engine car: Total 172 respondents form was accepted in this segment. Various make and model vehicles which includes Figo, Xcent, Swift Dzire, Sail LS ABS, Ertica, Altroz, Honda city, Nexon, Safari, Ciaz, MG Hector, Etios, Fortuner, Camry, Aspire VCT, I 20, Creata, Verna, Amaze, XUV 700, Verito D6, Bolt, Innova, Zest, Enjoy, Stingary, Cruser, Ritz, Wagnor, Alto 800, Maruti S Presso, Ignis, Grand Vitara, EECO Tour, Triber, Kick, Tiago, Kiger, KWID, NANO, Tigor, EON and SX4 etc. of different manufacturer such as Maruti, Suzzuki, Tata, Hyundai, Nishan, Mahindra, Ford, Toyota, Forcr, Chevrolet and KIA etc. were surveyed. Both diesel and petrol engine vehicles are included here. Average annual usage of the vehicle is 12,500 KM. Mileage of these vehicles found 12 to 23 KM per Litre. Ex-showroom price of these vehicles was found Rs 178000 to Rs 4617000. Registration and other taxes found Rs 19580 to Rs 614572. Misc expenses found Rs 5000 to Rs 61070. Annual insurance premium was found to be Rs 7218 to Rs 117703. The average annual repair/maintenance cost is found to be Rs 10203.

Battery Electric car: Total 71 respondents form was accepted in this segment. Various make and model vehicles which includes Nexon EV, Mahindra XUV 400, BYD Atto 3, Tigor EV, Kona, Xpress-T, E-verito, Mahindra E20, PmV EAS E, MG 2S EV, Altroz etc. of different manufacturer such as Tata, Mahindra, BYD, Hyundai and PMV etc. were surveyed. The average annual usage of the vehicle is 12,500 KM. Mileage of these vehicles was found to be 6.98 to 28.15 KWH per 100 KM. Ex-showroom price of these vehicles found Rs 479000 to Rs 2499000. Yearly insurance premium found Rs 23058 to Rs 130253. Average annual repair/maintenance cost found to be Rs 4282.

Internal combustion engine bus: Total 41 respondents form was accepted in this segment. Various make and model vehicles which includes Tata marcopolo, Tata 1612, Eicher 2050 D, Force Traveller 3350, Ashok Leyland 13.5M, Ttastarbus ultra, Tata citiride, SML Isuzu S7, Force Traveller 3700, Tata 709, Tata LPT 712, Ashok Leyland 4900, Volvo 9600, Eicher starline, Bharat Benz 1017, Mahindra Tourister, Mahindra cruziogrande, Tata starbus 909, Eicher 3011L, Eicher 2075H, Isuzu 5100, Ashok Leyland cheetah, Ashok Leyland sunshine, Ashok Leyland 3900 Tata starbus LP 810 etc. were surveyed. All buses surveyed were diesel engine vehicles. Average annual usage of the vehicle is 48000 KM. Mileage of these vehicles found to be 3 to 6 KM per Litre. Ex-showroom price of these vehicles was found to be Rs 2037464 to Rs 13000000. Average expenses on registration and other taxes were found to be Rs 4,58,378. The average annual insurance premium is found to be Rs 51989. The average annual repair/maintenance cost is found to be Rs 35000.

Battery Electric bus: Total 41 respondents form was accepted in this segment. Various model vehicles which include K9, K7, C6 and C9 etc. of M/s BYD Olectra etc. were surveyed. Average annual usage of the vehicle is 48000 KM. Mileage of these vehicles found to be 96 to 112 KWH per 100 KM. Ex-showroom price of these vehicles found Rs 20000000 to Rs 23000000. Average yearly insurance premium found to be Rs 51989. The average annual repair/maintenance cost is found to be Rs 50000.

Table-4.1 provides information on the number of internal combustion engine (ICE) and battery electric vehicles (BEV) across different vehicle categories (2-

wheeler, car, 3-wheeler, bus) in various cities in Maharashtra. Below is an interpretation of the data:

Total Vehicle Distribution

- Total Number of Vehicles: 682 vehicles across all categories and cities.
- Most Populated Vehicle Category:
- Car ICE: 172 vehicles (25.2% of total)
- 2W ICE: 128 vehicles (18.8% of total)
- 3W ICE: 133 vehicles (19.5% of total)

City-Level Analysis

- Pune: The city with the highest number of total vehicles (167), with significant representation across all vehicle categories, especially Car ICE (60 vehicles) and 2W ICE (25 vehicles).
- Nagpur: Second-highest number of vehicles (156), with notable BEV presence in all categories, particularly in the 2W BEV (25 vehicles) and Car BEV (25 vehicles) segments.
- Kolhapur: Third highest with 119 vehicles, with a strong presence in 2W ICE (48 vehicles) and Car ICE (45 vehicles).

BEV vs. ICE Distribution

- Overall ICE Dominance: ICE vehicles (474) significantly outnumber BEVs (208), comprising about 69.5% of the total vehicle count.
- BEV Concentration:
- Nagpur: The highest number of BEVs (78), with strong representation in all BEV categories.
- Pune: Second highest BEV count (52), particularly in the 2W BEV (16 vehicles) and Bus BEV (14 vehicles) categories.

Specific Observations

- Nagpur and Pune are leading cities for BEV adoption across various vehicle categories.
- Kolhapur and Mumbai are more ICE-dominated, with a limited presence of BEVs.
- Smaller cities like Beed, Wardha, Amravati, and others show very limited adoption of both ICE and BEV vehicles.

Category-Level Insights

- 2W Vehicles: Total 2W ICE (128) outnumber 2W BEVs (74), but cities like Nagpur and Pune show strong 2W BEV presence.
- Cars: Significant difference between Car ICE (172) and Car BEV (71), indicating that ICE cars still dominate the market.
- 3W Vehicles: Like 2W and cars, 3W ICE (133) are more prevalent than 3W BEVs (40), though BEVs are present in a few key cities like Nagpur and Pune.
- Buses: Lower overall presence in the data, with Bus ICE (41) slightly outnumbering Bus BEV (25).

Therefore, ICE vehicles still dominate across most cities and categories in Maharashtra. BEVs show an emerging presence, especially in Nagpur and Pune, but adoption remains lower compared to ICE vehicles. Focus on BEV Growth could be directed towards cities with existing infrastructure and favorable adoption rates, such as Nagpur and Pune.

Table 4.1: Shows the details of data collection as per place

Place	2W ICE	2W BEV	Car ICE	Car BEV	3W ICE	3W BEV	Bus ICE	Bus bev	Total
Nagpur	4	25	30	25	38	24	6	4	156
Nashik	1	17	5	17	20				60
Mumbai	18	6	20	6	27		7	6	90
Solapur	19	6	5	6	19	3			58
Pune	25	16	60	16	5	6	24	14	167
Kolhapur	48		45		15	7	4		119
Beed	9		2		3				14
Amarbati					5				5
Wardha					1				1
Aurangabad								1	1
Ahamadnagar	1								1
Satara	2		2						4
Palghar	1								1
Jalgaon		1	3	1					5
TOTAL	128	74	172	71	133	40	41	25	682

Reliability Test Analysis Report

In our case, we want to check the reliability of our questionnaire which was primarily filled by **30 respondents out of 51** from all segments of auto industry.

The questions were grouped in the variables and further the option selected by the responded was and no of options were also noted, example in case of two-wheeler responds were as below Table 10. The data provided offers a detailed view of vehicle ownership and usage, focusing on both non-electric vehicles (non-EVs) and electric vehicles (EVs). For non-EVs, the survey covers various aspects including the type of vehicle, engine type, vehicle segment, purchase price, age, general use, average distance traveled daily, refueling time, fuel costs, refueling frequency, and servicing details. Respondents are also asked about their service location, annual servicing cost, issues faced, interest in switching to an EV, willingness to pay a higher purchase price for lower

monthly costs, and the availability of charging stations on their commuting routes.

For EVs, the survey includes questions about the make and model, battery capacity, charging time, charging location, range per charge, monthly kilometers driven, monthly power consumption cost, annual repair and maintenance costs, vehicle lifespan, battery replacement history, and battery life after replacement. Additionally, respondents provide suggestions for improvement, reasons for purchasing an EV, and the most important factors influencing their choice of EV, along with the purchase price of their electric vehicle. This comprehensive approach aims to capture a broad spectrum of user experiences and preferences, shedding light on both the practical and financial aspects of vehicle ownership.

All responses were noted, and mean was taken as per the below formula

K- no of respondents

$\sum s^2_y$ - Sum of the all the items of the variance

s^2_x- Variance of Total Score

α- Cronbach's alpha was calculated by below formula as shown in figure 1

Table 4.2: Shows the calculation for pilot study.

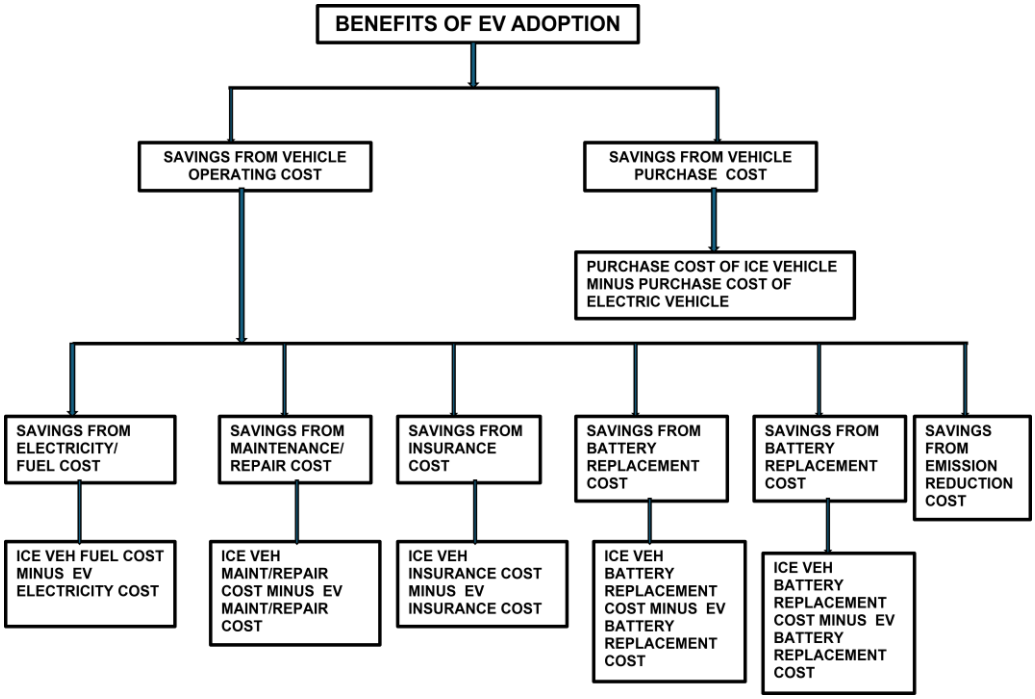
Variables	Description	Values	Internal Consistency
K	No of Items	30	**Good**
$\sum s^2_y$	Sum of the item variance	35.7044705	
s^2_x	variance of total score	220.733333	
α	Cronbach's alpha	0.87	

As indicated above our score is 0.87, hence we consider the system reliable.

4.10. COST-BENEFIT ESTIMATION OF EV ADOPTION: LIFE CYCLE COST MODEL

To evaluate the impact of various cost factors, the life cycle cost (LCC) of IC engine and battery electric vehicles such as two-wheelers, three-wheelers, car and bus are assessed here. The life cycle cost (LCC) of a vehicle refers to the

total cost of owning, operating, and maintaining the vehicle over its entire lifespan, from purchase to disposal. The major elements of the Life Cycle Cost (LCC) of a vehicle include all costs associated with the vehicle from its purchase to its disposal like initial purchase cost, salvage value, fuel or energy cost, repair and maintenance cost, insurance, taxes and fees, incentives and subsidy and battery replacement cost etc. In the present study, the life cycle cost of a vehicle is divided into five basic cost titles wherein one or more cost elements have been clubbed for ease of calculation. These are lifetime purchase cost, lifetime repair and maintenance cost, lifetime fuel or electricity cost and lifetime emission cost. Incentives and subsidy of electric vehicle has also been considered here as a cost title. Green, W. H et al. (2019) described Total Cost of Ownership of any vehicle has two components i.e. vehicle purchase cost comprising MSRP, purchase tax & subsidy and vehicle operating cost comprising fuel cost, insurance cost, maintenance cost and battery replacement cost. In study life cycle cost model has considered the concept of Total Cost of Ownership introduced by W. H et al. (2019). The difference between lifetime purchase cost of an IC engine vehicle and that of an electric vehicle is called lifetime savings from purchase cost. Similarly lifetime savings from fuel cost, lifetime savings from maintenance and insurance cost, lifetime savings from emission reduction cost, and lifetime savings from battery replacement cost are estimated. Sum of all savings i.e., lifetime savings from purchase cost, lifetime savings from fuel cost, lifetime savings from maintenance and insurance cost, lifetime savings from emission reduction cost, and lifetime savings from battery replacement cost is the benefit of adoption of an electric vehicle.



Vehicle purchase cost

The upfront cost of acquiring the vehicle is regarded as vehicle purchase cost. The vehicle purchase cost of an automobile vehicle in India varies widely depending on factors such as the brand, model, variant, and additional features. For an average Indian consumer, the vehicle cost comprises several components, including the ex-showroom price, on-road price, taxes, registration fees, insurance, and other associated expenses. Understanding these components can help in making an informed decision while buying a vehicle.

Ex-Showroom Price

The ex-showroom price is the cost of the vehicle itself, excluding taxes, insurance, and registration. It is the base price offered by the manufacturer to the dealer and serves as the foundation for the overall cost. In India, this price varies significantly depending on the type of vehicle.

Taxes and Fees

These are Vehicle-related taxes, including road taxes, registration fees, emissions fees, or any environmental levies. The Goods and Services Tax (GST) in India is applicable on all car purchases, and it generally falls between 28% to 43% depending on the car's category. Smaller cars, particularly those with an

engine capacity of less than 1,200cc, attract a lower tax rate, while higher-end and larger cars face the maximum tax bracket.

Registration Charges

Registration is mandatory to legally drive a vehicle in India, and the cost depends on the state where the vehicle is purchased. Registration fees typically range from ₹2,000 to a few lakh rupees depending on the engine capacity and vehicles value.

Incentive/subsidy

Government provides rebates, tax incentives, or subsidies to reduce the initial costs to encourage consumers for electric vehicles or environmentally friendly technologies. The Indian government offers various subsidies and incentives to promote the adoption of electric vehicles (EVs) as part of its broader goal to reduce carbon emissions and dependence on fossil fuels. This includes a direct subsidy on the purchase price of electric cars, two-wheelers, and buses, based on the vehicle's battery capacity and the overall range. For electric cars, subsidies can go up to ₹1.5 lakhs, depending on the model and the capacity of the battery. In addition to the FAME scheme, several state governments offer additional subsidies, such as reduced road tax, exemption from registration fees, and further cash rebates on EVs. These incentives make EVs more affordable and attractive to consumers, accelerating the transition to cleaner transportation in India. In Maharashtra, the **incentives and subsidies** for electric vehicles play a crucial role in reducing the overall purchase cost, making EVs more affordable for consumers. These include direct purchase subsidies, exemptions from road tax and registration fees, GST reductions, and financial support for charging infrastructure. Research studies like those by **Mahajan & Aggarwal (2021)** and **Rathi & Yadav (2020)** provide valuable insights into the effectiveness of these policies in promoting EV adoption in India.

Salvage value

Salvage**value** refers to the estimated residual value of a vehicle at the end of its useful life, typically after accounting for depreciation. In Maharashtra, the depreciation and salvage value of vehicles vary depending on the type of vehicle

(two-wheeler, three-wheeler, car, or bus) and whether it is conventional (IC engine) or electric. However, at the end of the useful life of any vehicle, it is sold or auctioned. Average salvage value or auctioned value is generally near about 6% of initial cost of the vehicle (Deepti Kapil, Central Pollution Control Board). Research studies like those by **Rathi et al. (2018),** Rajasekhar**et al. (2019),** Chakrabarti**et al. (2020),** and **Gupta et al. (2021),** provide useful insights into how depreciation and salvage values are calculated in India.

$$Salvage\ Value\ (SV)\ =\ Initial\ cost\ of\ Vehicle\ \times\ 0.06$$

The total **on-road price** can vary significantly depending on the vehicle type (electric or conventional) and the state in which it is purchased. Research in this area, such as the studies by **Sood et al. (2020)** and **Pande & Bhat (2021)**, provides valuable insights into these cost components and the financial feasibility of adopting electric vehicles in India.

$$\begin{aligned} Lifetime\ Purchase\ Cost\ (LTPC) \\ &= Vehicle\ ex-showroom\ price \\ &+ Registration\ charges\ +\ Lifetime\ Tax \\ &- Life\ Time\ subsidy\ and\ incentives\ -\ Salvage\ Value \end{aligned}$$

Fuel cost/electricity cost: The cost of fuel (for internal combustion engine vehicles) or electricity (for electric vehicles) is required to be considered for lifetime cost of the vehicle. This includes fuel consumption rates, electricity consumption rate, fuel price and local electricity prices. The lifetime fuel and electricity costs for vehicles vary widely based on the type of vehicle, whether conventional (internal combustion engine) or electric, and the energy consumption rates. These costs play a significant role in the overall cost of ownership and operational efficiency of vehicles.

Mileage of the vehicle is defined as the distance covered by consuming unit quantity of fuel or electricity. In India generally mileage is expressed in KM per Litre or KM per KWH.

$$\begin{aligned} Lifetime\ fuel\ consumption\ by\ the\ vehicle \\ &= (Life\ of\ the\ vehicle\ in\ KM)/\ Mileage\ (In\ Litre) \end{aligned}$$

$$Lifetime\ Fuel\ Cost\ (LTFC) = (Life\ of\ the\ vehicle\ in\ KM) \times (Cost\ of\ one\ Litre\ Fuel) / Mileage$$

For Electric Vehicle mileage is defined as distance covered by consuming unit quantity electricity. It is expressed as KM per KWH.

$$Lifetime\ Electricity\ Consumption\ (LTEC) = (Life\ of\ the\ vehicle\ in\ KM) / Mileage\ (In\ KWH)$$

$$Lifetime\ Electricity\ Cost\ (LTEC) = (Life\ of\ the\ vehicle\ in\ KM) \times (Cost\ of\ one\ KWH\ power) / Mileage$$

Repair/Maintenance Cost (RMC)

Maintaining and repairing vehicles is essential for ensuring their longevity, safety, and efficiency. In Maharashtra, where road conditions and driving patterns can vary, the costs of repair and maintenance depend on the type of vehicle (two-wheeler, three-wheeler, car, or bus) and whether it is conventional (internal combustion engine) or electric. Below is a brief overview of repair and maintenance costs for each type of vehicle. Item such as engine oil, gear oil, brake fluid, coolant, engine oil filter, air cleaner filter, brake pads/shoes, battery, tires, clutch plate, pressure plate, gears, sprocket, chain, suspension components, spark plug, injector, fuel injection pump, brake disc, brake drum, fuel motor, self-starter, alternator assembly, accelerator cable, clutch cable, UJ cross, solenoid switch, electric motors etc. are required to be replaced to ensure safe operation of any type of vehicle. Some of the items are replaced regularly on certain KM run of the vehicles. Some items are replaced when they become faulty. Some expenses are therefore required to be incurred for cost of the items, labor cost, calibration/ fitment cost. At times denting, painting and welding work also required to be carried out on vehicles due to occurrence of some damage. For traditional vehicles, maintenance costs are typically higher due to more complex engine systems, while EVs offer a lower overall maintenance cost due to fewer moving parts. Research studies, such as those by **Vasudevan et al. (2019)** and **Chakrabarti et al. (2021),**

provide valuable insights into the specific maintenance cost trends and comparisons across vehicle types in India.

$$Lifetime\ Repair/Maintenance\ Cost\ (LTRMC) = (Average\ annual\ repair/maintenance\ cost) \times Life\ of\ Vehicle\ in\ Years$$

Battery Replacement Cost

The cost of Li-ion battery of electric car and electric bus is very costly. Generally, Li-ion batteries are required to be replaced once in 5 to 7 years. Hence battery life for electric cars and buses is assumed to be 6 years. Due to the very high amount, the battery cost is separately considered here for any type of electric vehicle.

$$Lifetime\ Battery\ Replacement\ Cost\ (LTBRC) = (Cost\ of\ battery \times Vehicle\ life\ in\ years) / Average\ life\ of\ battery\ in\ years$$

Insurance Cost (IC)

Car insurance is also a vital cost factor, covering damage, accidents, theft, or any other unfortunate incidents. In India, third-party insurance is mandatory by law, while comprehensive insurance is optional but highly recommended for better coverage. The cost of insurance depends on the car's value, engine size, and the owner's no-claim bonus (NCB). The premium for automobile insurance in Maharashtra is calculated based on several factors such as **Type of Coverage, Vehicle Type, Age of the Vehicle, No Claim Bonus (NCB) and Vehicle Make and Model.** Comprehensive policies are more expensive than third-party insurance due to the broader coverage they offer. Two-wheelers, cars, and commercial vehicles have different premium structures. High-end or luxury vehicles attract higher premiums due to their higher repair costs. Older vehicles tend to have lower premiums since the insured value is lower. If the policyholder has not made any claims during the policy term, they are eligible for a discount on the premium for the next year.

$$Lifetime\ Insurance\ Cost\ (LTIC) = (Average\ annual\ insurance\ cost) \times Life\ of\ the\ vehicle\ in\ years$$

Emission reduction cost

This refers to the financial expense incurred to lower carbon emission. This cost can vary depending on vehicle type technology used, the existing energy mix, and government policies. The cost of reducing carbon emissions through the adoption of electric vehicles has been estimated at **$50 to $200 per ton of** CO_2 avoided, depending on the source of electricity and the scale of adoption. For example, a study by **Hao et al. (2021)** in *Energy Policy* suggests that the carbon reduction cost for electric vehicles can be around **$70 per ton of** CO_2 avoided in the context of China's transportation sector, where the electricity grid is increasingly decarbonized. According to a study by **Ghosh et al. (2020)** published in *Energy Policy*, the cost of reducing carbon emissions through the adoption of electric vehicles in India is approximately**$50 to $100 per ton of** CO_2 avoided, depending on the carbon intensity of the electricity grid. In areas where renewable energy share is higher, the cost-effectiveness improves. In India, where much of the grid still relies on coal, the reduction cost is somewhat higher compared to countries with cleaner grids.

$$Lifetime\ Emission\ Reduction\ Savings\ (LTERS): (Lifetime\ Emission\ of\ IC\ engine\ vehicle\ in\ ton - Life\ Time\ Emission\ of\ electric\ vehicle\ in\ ton) \times (Monetary\ value\ of\ per\ ton\ carbon\ reduction\ in\ Rupees)$$

$$Lifetime\ Operation\ Cost\ (LTOC) = Lifetime\ Fuel\ Cost\ (LTFC) / Lifetime\ Electricity\ Cost\ (LTEC) + Lifetime\ Repair/Maintenance\ Cost\ (LTRMC) + Lifetime\ Insurance\ Cost\ (LTIC) + Life\ time\ Battery\ Replacement\ Cost\ (LTBRC)$$

$$Lifetime\ Per\ KM\ Cost\ (LTPKMC) = (LTOC)/L$$

4.11. LIFETIME SAVINGS OF COST COMPONENTS

Lifetime Savings from Purchase Cost

This is the difference between the average purchase cost of an IC engine vehicle and battery Electric vehicle. Purchase cost includes ex-show room price, taxes and fees, registration charges, misc. expenses and salvage value.

$$Average\ purchase\ cost = Ex - show\ room\ price + taxes\ and\ fees + registration\ charges - salvage\ value.$$

Lifetime Savings from Fuel

This is the difference between the average lifetime cost incurred on fuel or electricity of an IC engine vehicle and battery Electric vehicle.

$$Average\ lifetime\ cost\ incurred\ on\ fuel\ for\ an\ IC\ engine\ vehicle = (Life\ of\ the\ vehicle\ in\ KM) \times (Cost\ of\ one\ Litre\ Fuel)/\ Mileage\ (KM\ per\ Litre)$$

For Electric Vehicle mileage is defined as distance covered by consuming unit quantity electricity. It is expressed as KM per KWH.

$$Lifetime\ Electricity\ Consumption = (Life\ of\ the\ vehicle\ in\ KM)/\ Mileage\ (KM\ per\ KWH)$$

$$Average\ lifetime\ cost\ incurred\ on\ electricity\ for\ an\ electric\ vehicle = (Life\ of\ the\ vehicle\ in\ KM) \times (Cost\ of\ one\ KWH\ Power)/\ Mileage$$

Lifetime Savings from Repair/Maintenance and Insurance

This is the difference between the average lifetime cost incurred on maintenance of an IC engine vehicle and battery Electric vehicle. Maintenance cost includes cost of lubricant oil, consumables, electrical items, all types of spare parts, changing of tyre and batteries, repair cost, service charges and labor cost etc. Replacement of batteries of electrical vehicles are also included in repair and

maintenance cost. Insurance cost incurred over the complete lifespan of vehicle is lifetime insurance cost.

$$Lifetime\ savings\ from\ maintenance = cost\ incurred\ on\ repair / maintenance\ and\ insurance\ of\ an\ IC\ engine\ vehicle - cost\ incurred\ on\ repair / maintenance\ and\ insurance\ of\ battery\ Electric\ vehicle$$

Lifetime Savings from Emission Reduction

This is multiplication of monetary value of one ton emission reduction and sum difference of average lifetime emission of an IC engine vehicle and electric vehicle. The U.S. Environmental Protection Agency (EPA) and other federal agencies use the Social Cost of Carbon (SCC) to estimate climate benefits of CO_2 emissions reduction. The value of the SCC is intended to capture the expense of climate change damages from carbon emissions including changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. Based on the technical support document prepared by the U.S. government interagency working group on Social Cost of Carbon, in 2015, the SCC per ton is $42.30. No such research data available in Indian context. SCC per ton in Indian context is assumed as Rs 3570 (1 $ = Rs 85).

$$Lifetime\ emission\ reduction\ in\ ton = Lifetime\ emission\ of\ IC\ engine\ vehicle\ in\ ton - Lifetime\ emission\ of\ electric\ vehicle\ in\ ton.$$

Monetary value of one ton emission reduction = Rs 3570

$$Lifetime\ savings\ from\ emission\ reduction = lifetime\ emission\ reduction\ in\ ton \times monetary\ value\ of\ one\ ton\ emission\ reduction$$

Lifetime Savings from Government Incentives: The Maharashtra government offers various subsidies and incentives to promote the adoption of electric vehicles (EVs). This includes a direct subsidy on the purchase price of electric

cars, two-wheelers, and buses. For electric cars, subsidies can go up to ₹1.5 lakhs, depending on the model and the capacity of the battery. In addition to the above, the government also offers additional subsidies, such as reduced road tax, exemption from registration fees, and incentives scrapping.

$$Lifetime\ savings\ from\ government\ incentives = direct\ subsidy\ on\ the\ purchase\ of\ electric\ vehicle + road\ tax\ reduction + registration\ fees\ exemption + incentives\ on\ scrapping\ of\ vehicle$$

Table 4.3: Various subsidy/incentives offered by government of Maharashtra are given below:

Type of vehicle	Subsidy on purchase new vehicle (Rs.)	Incentive on road tax and registration fee (Rs.)	Incentives on scrapping of vehicle (Rs.)
Battery Electric two-wheel vehicles	10000	8100	7000
Battery Electric three-wheel vehicles	30000	6000	15000
Battery Electric car	150000	187375	25000
Battery Electric bus	20000	187375	25000

4.12. TOTAL LIFETIME SAVINGS

This is sum of all savings i.e. lifetime savings from purchase cost, lifetime savings from fuel, Lifetime savings from maintenance and insurance, Lifetime savings from emission reduction, and Lifetime savings from government incentives due to adoption of an electric vehicle.

$$Total\ lifetime\ savings = lifetime\ savings\ from\ purchase\ cost + lifetime\ savings\ from\ fuel + Lifetime\ savings\ from\ maintenance\ and\ insurance + Lifetime\ savings\ from\ emission\ reduction + Lifetime\ savings\ from\ government\ incentives$$

Table 4.4: Based on survey, life of vehicles assumed is as under:

Type of Vehicle	Life in Year	Life in KM
Internal combustion engine two-wheel vehicles	15	90,000
Battery Electric two-wheel vehicles	15	90,000
Internal combustion engine three-wheel vehicles	15	2,88,000
Battery Electric three-wheel vehicles	15	2,88,000
Internal combustion engine car	15	1,50,000
Battery Electric car	15	1,50,000
Internal combustion engine bus	15	7,20,000
Battery Electric bus	15	7,20,000

In Maharashtra, the average rate of Diesel and Petrol is assumed as Rs 90/Ltr and Rs 100/Ltr respectively. Average rate of electricity for charging purposed is assumed as Rs 7.40/KWH.

Chapter 5
Results and Discussion

CHAPTER 5
RESULTS AND DISCUSSION

ADOPTION INTENTION OF ELECTRIC VEHICLES IN MAHARASHTRA.

5.1. PRELIMINARY ANALYSIS

The dataset comprises 390 observations, capturing demographic, economic, and behavioral variables (see table 5.1). On average, the gender variable (Gen) indicates a low proportion of a particular category (likely female, coded as 1) at 13.11%, with significant variation. Occupational levels ($Ocup$) average at 2.35, suggesting a moderate skill or employment level on a scale from $1\ to\ 4$. Income (Inc) shows high variability, with an average of 43007.65 units but a widespread ($14{,}000\ to\ 110{,}000$). Respondents are relatively mature, with an average age of approximately 39 years, ranging from $20\ to\ 60$ years. Education (Edu) is moderately high, averaging 12.7 years of schooling (secondary to early higher education). The willingness to pay for higher price ($Wtp - hp$) averages at 45.75%, indicating nearly half the sample expresses support. Technological factor (Tf) averages at 3.19 on a scale of $2\ to\ 5$, suggesting, respondents likely view advancements in EV technology (e.g., range, charging speed, and reliability) as significant motivators. The policy and support (Ps) scores are moderate, with a mean of 0.46 on an undefined scale. On a scale of $3\ to\ 5$, it has a mean of 3.9835, suggesting that respondents have a usually high level of environmental concern. The low standard deviation of 0.3597 indicates that there is little fluctuation in most respondents' levels of environmental concern. The low standard deviation of 0.3597 indicates that there is little fluctuation in most respondents' levels of environmental concern. Environmental consciousness serves as a driving force for embracing electric vehicles. Individuals with a strong environmental ethic demonstrate a propensity towards selecting green technologies like EVs to diminish their carbon emissions and promote environmental sustainability.

Table 5.1: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Gender	390	0.1311	0.3379	0	1
Occupation	390	2.3470	1.2058	1	4
Income	390	43007.65	27181.45	14000	110000
Age	390	39.08	8.59	20	60
Education	390	12.6863	1.9634	10	17
Willing to Pay Higher Price	390	0.4575	0.4988	0	1
Technology Factor	390	3.1965	0.6773	2	5
Policy and Support	390	3.4651	0.8285	1	5
Environmental Concern	390	4.004	0.3438	3	5
Attitude	390	3.1625	0.5913	2	5
Perceived Behaviour Control	390	3.2097	0.5259	2	4
Subjective Norm	390	3.3752	0.4303	2	4

Electric Vehicle Adoption: Opportunities and Issues

The survey data presents in Tabel 5.2 insights into the perspectives and experiences of individuals regarding ICE (Internal Combustion Engine) and BEV (Battery Electric Vehicles). Here's an interpretation of the key findings:

High Running Costs (45.44%) and Regular Maintenance Needs (35.24%) are the major concerns. Frequent Breakdowns (5.10%) and other issues (14.23%) are less common but still notable. 47.77% of ICE users are interested in switching to electric vehicles, 39.70% are not interested, while 12.53% are uncertain (Maybe). This shows a strong potential market for BEVs, though nearly 40% of ICE users remain reluctant. Only 25.69% of ICE users are willing to pay more for BEVs, 66.24% are not willing to pay a premium, indicating price sensitivity remains a significant barrier, 8.07% are uncertain**.**

TV or Newspapers (55.20% ICE, 46.19% BEV) are the primary sources of information, followed by Friends or Relatives (27.81% ICE, 27.14% BEV). Dealers play a smaller role but are still a notable source of information for

16.99% of ICE and 26.67% of BEV users. Nearly unanimous support (99.36% ICE, 100% BEV) for having electric vehicles on the road, indicating broad acceptance of the concept.86.62% of ICE users are aware of the benefits of BEVs, with 100% awareness among BEV users. 13.38% of ICE users lack awareness, suggesting an opportunity for further education.

Environmentally friendly and cost-effective charging are the top perceived benefits for both ICE and BEV users. Less noise, government subsidies, and new technology also rank high, though BEV users are slightly more inclined to consider these as benefits. Environmental benefits (15.29% ICE, 15.24% BEV) and charging cost savings (14.01% ICE, 14.29% BEV) are the top priorities. Less noise, status symbols, and government subsidies are also important, though to a lesser extent.

Battery life and cost (23.78% ICE, 31.43% BEV) are the top concerns. Initial cost (22.08% ICE, 16.19% BEV) and charging station availability (17.62% ICE, 20.00% BEV) are significant barriers. Awareness (13.38% ICE, 8.10% BEV) and range anxiety (7.01% ICE, 16.67% BEV) are additional concerns. At-home charging is the most preferred option for both ICE (55.84%) and BEV (53.33%) users. Workplace (18.47% ICE, 18.33% BEV) and public charging stations (25.69% ICE, 28.33% BEV) are also considered viable options.77.07% of ICE users and 58.10% of BEV users believe BEVs are more expensive than ICE vehicles. 22.93% of ICE users and 41.90% of BEV users do not share this perception, indicating that BEV users are more aware of the long-term cost benefits.86.20% of ICE users and 56.67% of BEV users report there are no charging stations in their area, highlighting a significant infrastructure gap. 7.22% of ICE users and 24.76% of BEV users have observed one charging station, while 6.58% of ICE users and 18.57% of BEV users have seen two or more.

From the above interpretation of data, we conclude the key challenges to BEV adoption include high initial costs, battery life concerns, and a lack of charging infrastructure. However, there are significant opportunities as interest in BEVs is strong, particularly due to their environmental benefits and fuel cost savings.

Younger and more educated demographics show the most interest. Enhancing awareness and improving infrastructure can further boost BEV adoption.

Table 5.2: Electric Vehicle Adoption Issues

	Issues	Number	Percentage
1	What sort of issues are you facing with your current vehicle?		
	High Running Cost	177	45.44
	Regular Maintenance Needs	138	35.24
	Frequent Breakdowns	20	5.10
	Others	55	14.23
	Total	390	
2	Interested in switching to an electric Vehicle?		
	Yes	186	47.77
	No	155	39.70
	May be	49	12.53
	Total	390	
3	Willing to pay a higher purchase price for an electric Vehicle?		
	Yes	101	25.69
	No	258	66.24
	May be	31	8.07
	Total	390	
4	From where you get to know about electric Vehicle?		
	Friends or relatives	109	27.81
	TV or New Papers	215	55.20
	Dealer	66	16.99
	Total	390	
5	Do you think there should be electric Vehicle on the road?		
	Yes	388	99.36
	NO	2	0.64
	Total	390	
6	Do you know benefits of electric Vehicle?		

	Issues	Number	Percentage
	Yes	338	86.62
	No	52	13.38
	Total	390	
7	Please allot priority number for benefits of electric Vehicle		
	Environment friendly as no gas emitted from exhaust.	60	15.29
	Charging Cost less than Petrol/Diesel	55	14.01
	Less Noisy	49	12.53
	Status Symbol	36	9.34
	Govt Subsidy and incentives	52	13.38
	New Technology	44	11.25
	Easy registration	41	10.62
	Easy to drive	53	13.59
	Total	390	100
8	What might be the reason people are not interested in electric Vehicle according to you?		
	Awareness	52	13.38
	Initial Cost	86	22.08
	Charging Station	69	17.62
	Battery life and cost	93	23.78
	Maintenance	63	16.14
	Range	27	7.01
	Total	390	
9	Where would you prefer to charge your electric vehicle if you were to buy one electric Bus in future.		
	At home	218	55.84
	At Workplace	72	18.47
	Charging Station	100	25.69
	Total	390	
10	Do you think electric Vehicle is having more cost than diesel/petrol?		
	Yes	300	77.07
	No	90	22.93
	Total	390	

	Issues	Number	Percentage
11	How many charging station you have observed in your area?		
	One	28	7.22
	Two or more	26	6.58
	No Charging Station	336	86.20
	Total	390	

Normality results

Kolmogorov-Smirnov Test (K-S): The p-values are 0.000 (less than 0.05) for every variable (EC1, EC2, A1, SN1, etc.), suggesting that none of the variables have a normal distribution. Shapiro-Wilk Test (S-W): This test also confirms that the data is not normally distributed, as all variables have a p-value of 0.000. Both test's p-value is significant ($p < 0.05$), indicating that none of the variables' data is distributed normally (Table- 5.3). This implies that, depending on the objectives of the study, non-parametric tests should be taken into consideration and parametric tests—which presume normality—may not be suitable for analysis.

Table 5.3: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df.	Sig.	Statistic	Df.	Sig.
EC1	0.217	390	0.000	0.783	390	0.000
EC2	0.202	390	0.000	0.797	390	0.000
EC3	0.206	390	0.000	0.790	390	0.000
EC4	0.212	390	0.000	0.789	390	0.000
EC5	0.216	390	0.000	0.788	390	0.000
A1	0.204	390	0.000	0.880	390	0.000
A2	0.211	390	0.000	0.904	390	0.000
A3	0.177	390	0.000	0.915	390	0.000
A4	0.219	390	0.000	0.878	390	0.000
SN1	0.282	390	0.000	0.868	390	0.000
SN2	0.217	390	0.000	0.909	390	0.000
SN3	0.241	390	0.000	0.891	390	0.000
SN4	0.251	390	0.000	0.882	390	0.000
PBC1	0.212	390	0.000	0.905	390	0.000
PBC2	0.291	390	0.000	0.848	390	0.000
PBC3	0.278	390	0.000	0.853	390	0.000

AdIn1	0.233	390	0.000	0.891	390	0.000
AdIn2	0.192	390	0.000	0.911	390	0.000
AdIn3	0.194	390	0.000	0.912	390	0.000
PS1	0.302	390	0.000	0.838	390	0.000
PS2	0.277	390	0.000	0.864	390	0.000
PS3	0.203	390	0.000	0.914	390	0.000
TF1	0.198	390	0.000	0.896	390	0.000
TF2	0.206	390	0.000	0.909	390	0.000
TF3	0.289	390	0.000	0.854	390	0.000
TF4	0.244	390	0.000	0.890	390	0.000

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy

Strong enough correlations between variables for factor analysis are indicated by a significant p-value. This test is significant because Sig. = 0.000, which indicates that factor analysis is suitable (Table-5.4). The sample is sufficient for factor analysis, according to the KMO value (0.821).

Table 5.4: Measure of Sampling Adequacy

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**0.821**
Bartlett's Test of Sphericity	Approx. Chi-Square	3786.263
	Df	390
	Sig.	0.000

Common Method Bias

According to Podsakoff and Organ (1986), Common Method Bias (CMB) is the phenomenon whereby connections between constructs are skewed because of employing the same assessment technique. The researcher used Harman's Single Factor Test to address this. The maximum variance in this investigation that could be accounted for by a single factor was 19.928% (Table-5.5), which is far less than the 50% cutoff, suggesting that CMB is not a problem and permitting additional research.

Table 5.5: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	% of Variance	Cumulative %
1	5.181	19.928	19.928	19.928	19.928
2	3.461	13.311	33.239	13.311	33.239
3	1.729	6.649	39.887	6.649	39.887
4	1.634	6.284	46.172	6.284	46.172
5	1.505	5.790	51.962	5.790	51.962
6	1.154	4.440	56.402	4.440	56.402
7	1.034	3.976	60.378	3.976	60.378
8	0.991	3.813	64.191		
9	0.922	3.544	67.735		
10	0.891	3.427	71.162		

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	% of Variance	Cumulative %
11	0.860	3.308	74.471		
12	0.828	3.184	77.654		
13	0.743	2.858	80.513		
14	0.676	2.601	83.114		
15	0.618	2.375	85.489		
16	0.573	2.204	87.694		
17	0.476	1.831	89.525		
18	0.467	1.795	91.320		
19	0.428	1.644	92.964		
20	0.399	1.534	94.498		
21	0.377	1.450	95.948		
22	0.277	1.065	97.013		
23	0.247	0.949	97.962		
24	0.213	0.819	98.781		
25	0.160	0.616	99.397		
26	0.157	0.603	100.000		

Statistical analysis

The partial least squares method is used in the investigation. This method, known as structural equation modeling, or SEM, has been used to evaluate hypotheses and determine whether survey data fits well into the study's suggested model. In PLS, the model is tested in two stages: first, the constructs are tested for validity and reliability; second, the link between the constructs is illustrated, and finally, the overall model fit is examined.

Measurement model testing: The study has adhered to the recommendations made by Hair et al. (1998) for evaluating the validity and reliability of the constructs. All the items in our study loaded over the required threshold level, which is greater than 0.70, which is the recommended factor loading. Cronbach

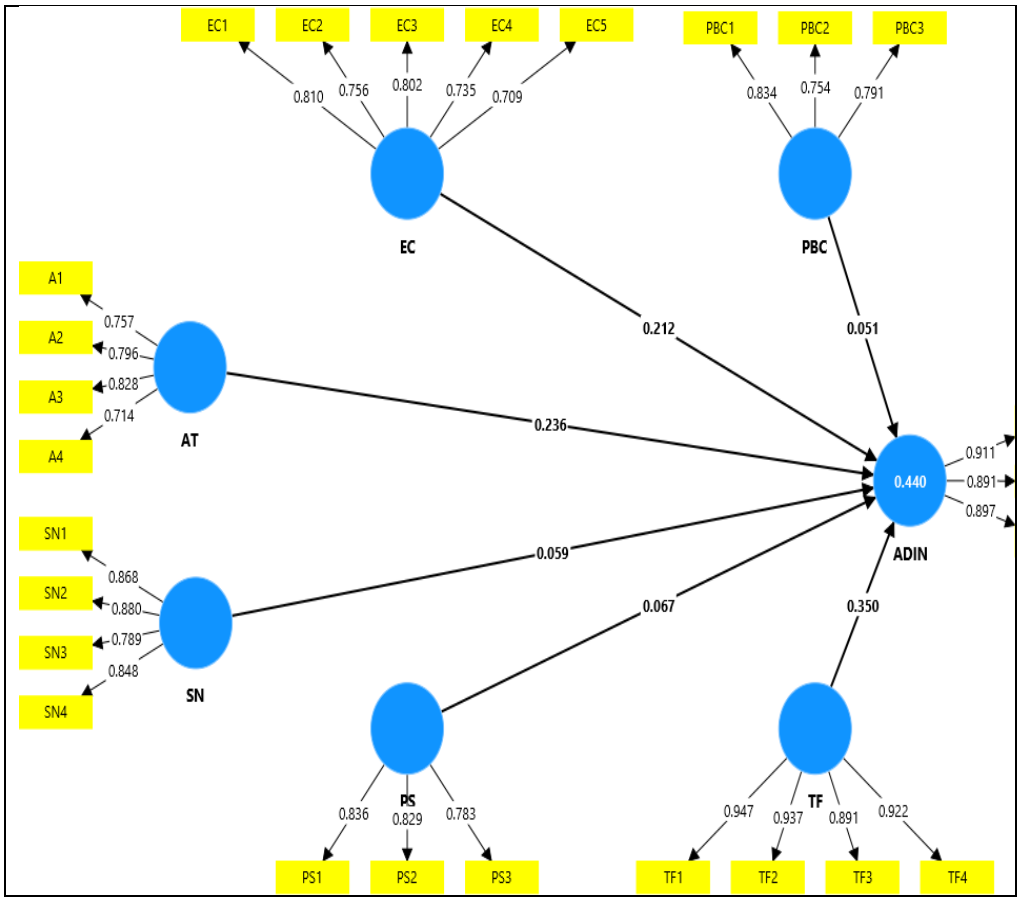
alpha and composite reliability can be used to quantify construct dependability, according to Fornell and Larcker (1981). Details of the reliability values are displayed in Table 5.6 and Figure 5.1.

Table 5.6: Reliability values

Constructs	Items	Factor Loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Attitude toward adopting an EV	**A1**	0.757	0.78	0.857	0.601
	A2	0.796			
	A3	0.828			
	A4	0.714			
Intention to adopt an EV	**AdIn1**	0.911	0.882	0.927	0.809
	AdIn2	0.891			
	AdIn3	0.897			
Environmental Concern	**EC1**	0.810	0.82	0.874	0.582
	EC2	0.756			
	EC3	0.802			
	EC4	0.735			
	EC5	0.709			
Perceived behavioural control	**PBC1**	0.834	0.712	0.836	0.63
	PBC2	0.754			
	PBC3	0.791			
Policy and Support	**PS1**	0.836	0.75	0.857	0.666
	PS2	0.829			
	PS3	0.783			
Subjective Norm	**SN1**	0.868	0.87	0.91	0.717
	SN2	0.880			
	SN3	0.789			
	SN4	0.848			
Technological Factor	**TF1**	0.947	0.943	0.959	0.855
	TF2	0.937			

Constructs	Items	Factor Loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
	TF3	0.891			
	TF4	0.922			

Figure 5.1: Outer Model SEM



Reliability and construct validity are very separate ideas. It shows that a tool truly measures the latent variable that it is theoretically supposed to measure. Accordingly, measurement accuracy is a concern of construct validity (Hair et al. 1998). Convergent validity (a) and discriminant validity (b) support it. Items of the construct should have a large common variance, or converge strongly, according to the first component of convergent validity. Standardised item loading can be used to determine the value of the average variance extracted (AVE), which is used to establish convergent validity:

$$AVE = \sum_{i=1\ to\ n/n^*} \lambda^2$$

Although the measures of environmental concerns did not converge as strongly as those of other variables, all the AVE values in this study are greater than 0.50 (Hair et al. 1998), indicating appropriate convergence. When a latent variable is observed differently from unrelated theoretical notions, it is said to have discriminant validity. According to Hair et al. (1998), the squared correlation value between two constructs must be less than their AVE to demonstrate discriminant validity. The fundamental reasoning is that a latent variable must be able to explain variation more effectively than others. The discriminant validity is demonstrated by the fact that AVE values exceed their squared correlation, as indicated in Table 5.7.

Table 5.7: AVE and squared correlation estimates

	ADIN	AT	EC	PBC	PS	SN
ADIN						
AT	0.511					
EC	0.487	0.222				
PBC	0.369	0.233	0.476			
PS	0.474	0.255	0.811	0.411		
SN	0.398	0.424	0.439	0.196	0.396	
TF	0.582	0.385	0.264	0.348	0.352	0.337

Structural model testing

Table 5.8 presents the findings of a structural model study we performed after getting a good measurement model. All the path coefficients loaded significantly and pointed in the desired direction, as the table shows, suggesting that AT, EC, PBC, PS, SN and TF had a positive relationship with the EV adoption.

The intention of consumers to embrace EVs is positively and strongly correlated with their level of environmental concern. When consumers' concerns about the environment grow, EVs are typically promoted more widely (Mondéjar-Jiménez et al., 2011). The path coefficient from environmental concern to EV adoption intention, ($\beta = 0.212$, $p < 0.01$), according to the regression analysis results (Table 5.8). It indicates that consumers' environmental concerns have a significant impact on adoption intention than policy initiatives. Similarly, the coefficient of technology factor is positive and significant revealing customers preference and intention to adopt EV. The magnitude of coefficient is stronger than environmental factor and policy factor.

Table 5.8: Hypothesis Testing

Path	Path Coefficients	T-statistics	Hypothesis
AT → AdIn	0.236	3.630	H1 supported
EC → AdIn	0.212	3.593	H2 supported
PBC → AdIn	0.051	3.442	H3 supported
PS → AdIn	0.067	3.722	H4 supported
SN → AdIn	0.059	2.101	H5 supported
TF → AdIn	0.350	3.623	H6 supported

Most the study's empirical findings support the conclusions of the body of existing research while offering fresh perspectives tailored to the Indian market and its difficulties. For instance, our study supports the favorable effect that attitude plays in the adoption of EVs, which has been emphasized by Hidrue et al. (2011), Jensen et al. (2013), and Li et al. (2018). Our findings are consistent with those of Han et al. (2010), Axsen and Kurani (2012), Wang et al. (2014), Dhar et al. (2015), and Shalender and Yadav (2018), who all found that subjective norms have a significant impact on attitudes and adoption intentions. Additionally, the study confirms the significance of perceived behavioural control in adopting electric vehicles, which has been noted by Ajzen (1991) and Castanier et al. (2013).

Measurement model assessment for Collinearity issues

The Variance inflation factor (VIF) is often used to evaluate collinearity. Ideally, the VIF values should be close to 3 and lower. The VIF values of the outer model are presented in Table-5.9 and all values are below 3 for each factor.

Table 5.9: VIF Values

	VIF
A1	1.631
A2	1.455
A3	1.959
A4	1.378
AdIn1	2.67
AdIn2	2.41
AdIn3	2.384
EC1	1.796
EC2	1.55

	VIF
EC3	1.829
EC4	1.554
EC5	1.463
PBC1	1.38
PBC2	1.429
PBC3	1.37
PS1	1.536
PS2	1.537
PS3	1.44
SN1	3.449
SN2	2.318
SN3	2.026
SN4	3.14
TF1	2.542
TF2	2.81
TF3	2.622
TF4	2.655

5.1.1. PREDICTIVE RELEVANCE OF INNER MODEL

Assessing a model's predictive relevance is a crucial aspect of the study, as it demonstrates the model's ability to predict outcomes beyond the sample data, highlighting its out-of-sample predictive accuracy. A model with excellent prediction accuracy is indicated by a Q^2 value that is closer to 0.35 or above.

Table 5.10: Predictive Relevance of model

R SQUARE	0.444
Q SQUARE	0.392

5.1.2. TESTING OF THE STRUCTURAL MODEL

In order to assess the model fit or predictive relevance of the model, the researcher has used SRMR and NFI values.

Table 5.11: Testing of the structural model

SRMR	0.081

NFI	0.913

The Standardized Root Mean Square Residual (SRMR) measures model fit by comparing the observed and estimated correlation matrices. An SRMR value below 0.10 indicates good fit (Hu & Bentler, 1999), and the model's SRMR of 0.081 confirms this. The Normed Fit Index (NFI) compares the model's Chi-square value to a standardized benchmark, ranging between 0 and 1, with values ≥0.9 indicating good fit (Lohmöller, 1989). The model's NFI of 0.913 also confirms a good fit. Thus, model fit is supported by both SRMR and NFI.

Robustness Check

Data were analyzed to identify important determining factors behind respondents' WTS to EV. Findings from the Logit analysis suggest that except gender all other socio-economic determinants significantly affect customers' willingness to adopt EV at either 1 or 5 percent level of probability. Interestingly three factors used in the extended model like environmental concern, technology and policy initiatives also significantly revealed respondents' willingness to adopt EV in Maharashtra. The magnitude of the coefficient of Policy and support factor is higher assuming that this factor has major implications for EV adoption in the state. Since EV adoption will bear extra cost for the customers and this study used willingness to pay higher cost as an independent variable as well. Results reveal that the factor revealed a positive and significant impact on customers' willingness to adopt EV.

Table 5.12: Summary outcomes from the Multivariate Logistic Regression analysis

Variables	Coeff./s.e	P>Z	[95% Conf. Interval]
Gen	0.2336 (0.3548)	0.510	-0.4618-0.9290
Ocup	0 .4566*** (0.1703)	0.007	0.1228-0.7904
Inc	0.0172** (0.0078)	0.014	-0.00003-1.8206
Age	0.1211*** (0.0318)	0.000	0.0587-0.1835
Wtp_hp	6.1276*** (0.9901)	0.000	4.1869-8.0683
Ec	0 .0438***	0.001	-0.6272-0.7148

	(0.01423)		
Tf	0.1557** (0.0823)	0.029	-0.3284-0.6400
Ps	0.2770*** (0.0739)	0.000	-0.1576-0.7117
cons.	4.0671** (2.1460)	0.058	-8.2732-0.1390
$\boldsymbol{Wald\chi^2}$		74.45	
$\boldsymbol{Prob > \chi^2}$		0.0000	
Log pseudolikelihood		-137.11177	
$\boldsymbol{Pseudo\ R^2}$		0.4958	
N		390	

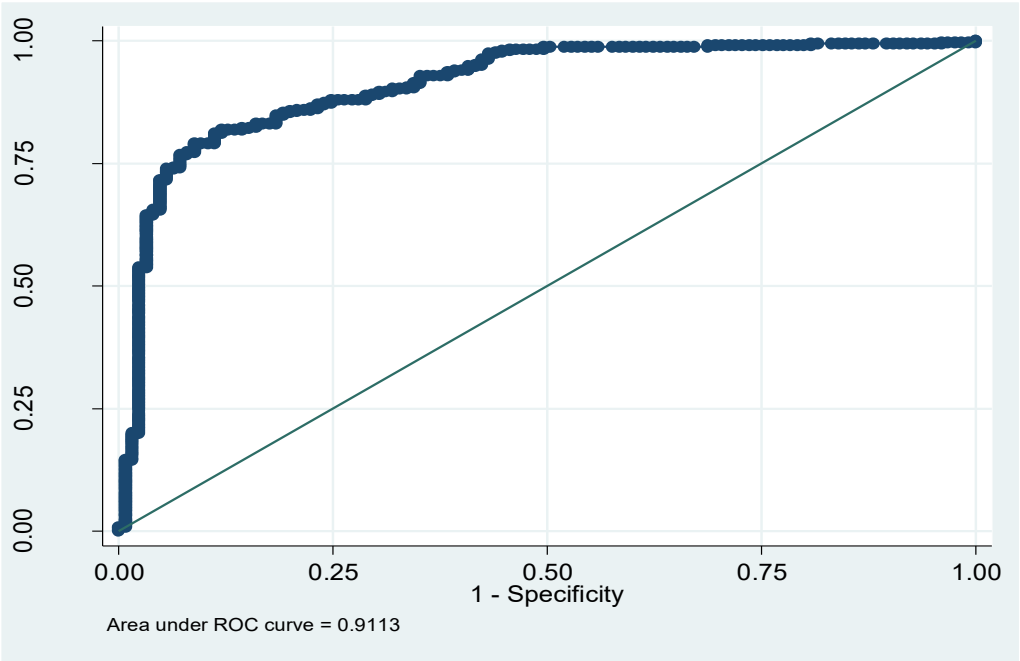
Discriminatory Performance of the Model

Statistical tests like -2log-likelihood, McFadden's Adjusted[1] R^2 and Area under ROC Curve were carried out to understand overall explanatory power and suitability of the Logistic Model used in determining factors for respondents' willingness to shift and adopt EV. Findings from the model support the use of a Logit Model. The overall explanatory power of the selected independent variables was found to be quite satisfactory. A value of -137.11 for the log *pseudolikelihood* was found to be reasonably good for this model. Similarly, *McFadden's Adjusted* R^2value of 0.495 and the '*Area under ROC Curve*'[2] as high as 0.9113, were well-accepted and found to be satisfactory with a high goodness of fit. This implies that the model was well-fitted, and findings based on this model have the capacity to be used with high accuracy in explaining people's WTS behavior in the present context

[1] This is also known as the likelihood-ratio index. It compares the likelihood for the intercept only model to the likelihood for the model with predictors adjusted by the number of parameters in the model.

[2] A closeness of the area under ROC curve to 1 refers to high diagnostic accuracy of the model, while a smaller value indicates a poor discriminatory power of the model (Kleinbaum and Klein, 2010; p. 357). The explained variable, willingness to pay, used in the fitted model is binary in nature and takes values '0' and '1'. If a household expresses its willingness to pay for the proposed service, then it is classified as '1', if otherwise, then '0'. In such cases, when Logit or Probit model is used, the goodness of fit is of secondary importance (Gujarati, 2007; p. 619).

Figure 5.2: ROC Curve



Conclusion

From the preceding paragraphs, based on diagnostic tests such as normality, sampling adequacy, common method bias, total variance, indicator reliability, internal consistency reliability, convergent validity, discriminant validity, robustness check and SEM result, it can be concluded that selected model is overall fit and all hypotheses are supported.

Hypothesis 1 Based on the results of hypothesis testing 1, it can be concluded that intention to adopt electric vehicles is positively correlated with the adoption attitude. This shows that the potential consumers have positive attitude regarding electric vehicles and potential consumers have strong desire to adopt electric vehicles.

Hypothesis 2 Based on the results of hypothesis testing 2, it can be concluded that the inclination to embrace EVs is strongly correlation with the effect of subjective norms. This shows that the family, friends and social pressure of potential consumers have strong desire to adopt electric vehicles

Hypothesis 3 Based on the results of hypothesis testing 3, it can be concluded that the intention to switch to electric vehicles is positively correlated with

perceived behavioral control. This shows that the potential consumers have higher level of ease to adopt electric vehicles.

Hypothesis 4 Based on the results of hypothesis testing 4, it can be concluded that environmental concern has a positive effect on adoption intention of EVs. This shows that the prospective consumers believe that adoption of electric vehicles will stop damage to environment like continuous increase of emission and depletion of fossil fuels due to transportation sector.

Hypothesis 5 Based on the results of hypothesis testing 5, it can be concluded that policy and support is positively correlated with adoption intention of EVs. This shows that government policy and support such as incentives, proper infrastructure and FAME scheme will motivate and attract the potential consumers to adopt electric vehicles.

Hypothesis 6 Based on the results of hypothesis testing 6, it can be concluded that technological advancement is positively correlated with adoption intention of EVs. This shows that the potential consumers will adopt electric vehicles with EVs technological advancement such as improvement of battery life, vehicles range, battery material, fast charging etc.

5.2. IMPACT OF EV ADOPTION ON EMISSION REDUCTION

Descriptive Statistics

Tabel 5.13 provides detailed information on the demographics, educational background, occupation, income, and fuel preferences of individuals using different types of vehicles (Two-Wheeler, Car, Auto Rickshaw, and Bus) categorized into ICE (Internal Combustion Engine) and BEV (Battery Electric Vehicles). Below is an interpretation of the data:

Gender Distribution

With 601 men making up 88% of the total respondents and 81 women making up only 12%, the data clearly shows a male preponderance among car users. Although a sizable portion (199 users) have switched to battery electric vehicles (BEVs), male users still primarily utilise internal combustion engine (ICE) automobiles, with 402 persons utilising ICE models. On the other hand, women

are mostly found using ICE vehicles, such as cars and two-wheelers, and they are not very likely to utilise BEVs—just 11 out of 81 vehicles used by women are electric. This demonstrates the gender gap in car ownership and BEV adoption rates.

Age Distribution

The bulk of users, or 53% of all responders (363 people), are in the 30- to 40-year-old age range. With a penchant for cars and two-wheelers, this group shows a balanced mix of internal combustion engine (ICE) vehicles (241 users) and battery electric vehicles (BEVs) (122 users). 23% of users (158 people) are in the 18–30 age range, and they embrace BEVs at a higher rate, especially for two-wheelers and autorickshaws. In contrast, 24% of users (161) are in the 40–60 age range, with a significant preference for ICE vehicles (126 users) and a comparatively low adoption rate for BEVs (35 users). Interestingly, no one over 60 is shown, which may indicate that they use cars infrequently or were not included in the statistics.

Education Distribution

12th Pass: Largest group (45% of total), showing a strong presence in both ICE and BEVs. Graduates: 33% of total users, with a notable number of BEV users (74 out of 221). 10th Pass and Postgraduate: Lower representation but still engaged, especially in Two-Wheeler and Auto Rickshaw categories.

Occupation Distribution

Service Sector: 46% of total users, with a mix of ICE (234) and BEVs (78). Self-Employment: 34% of users, with a higher BEV adoption rate (117 BEVs out of 228 total vehicles). Students and Others/Drivers: Represent 20% of the total, with minimal BEV usage.

Income Distribution

20,000 to 50,000 INR: Largest income group (39%), with balanced ICE (170) and BEV (97) usage. Up to 20,000 INR and 50,000 to 1,00,000 INR: Represent similar portions (27% each), with significant BEV adoption in the higher income bracket.1,00,000 INR and Above: Smallest group (8%), but with notable BEV presence (20 BEVs out of 52 vehicles).

Fuel Usage

Petrol is used by 47% of the total users (319 vehicles), with strong representation in Two-Wheelers, Cars, and Auto Rickshaws. Diesel: 22% of users (153 vehicles), primarily in Cars and Buses. Electricity: 31% of users (210 vehicles) – This indicates a growing BEV presence, especially in the Two-Wheeler and Car segments.

Vehicle Ownership

Vehicle Owners: 78% of total users (529 vehicles), with a balanced mix of ICE (345) and BEVs (184). Non-Owners (Drivers): 22% of total users (153 vehicles), primarily using ICE vehicles (127). ICE vehicles (472 vehicles) still dominate the market, accounting for 69% of the total vehicles. BEV adoption is significant (210 vehicles, 31%) but still growing, with notable adoption in Two-Wheelers and Cars. Males, particularly those aged 30-40, service sector employees, and those earning between 20,000 to 50,000 INR, represent the largest user group across vehicle types**.**Petrol remains the most used fuel, but electricity usage is gaining traction, reflecting the shift towards BEVs**.**

Table 5.13: General information, Summery

Number of Persons		Two-Wheeler		Car		Auto Rickshaw		Bus		Total ICE	Total BEV	Grand Total	%
		ICE	BEV	ICE	BEV	ICE	BEV	ICE	BEV				
Gender	**Male**	110	65	120	71	131	40	41	23	402	199	601	88
	Female	18	9	52	0	0	0	0	2	70	11	81	12
		128	74	172	71	131	40	41	25	472	210	682	
Age (Years)	**18-30**	58	31	20	5	20	11	7	6	105	53	158	23
	30-40	51	38	106	38	58	29	25	17	241	122	363	53
	40-60	19	5	46	28	53	0	8	2	126	35	161	24
	Above 60	0	0	0	0	0	0	0	0	0	0	0	0
												682	
Education	**10th pass**	26	8	1	0	53	13	10	1	90	22	112	16
	12th pass	53	28	72	30	70	21	14	20	209	99	308	45
	Graduate	36	33	86	33	8	6	17	2	147	74	221	33
	Postgraduate	13	5	13	8	0	0	0	2	26	15	41	6
												682	

Number of Persons		Two-Wheeler		Car		Auto Rickshaw		Bus		Total ICE	Total BEV	Grand Total	%
		ICE	BEV	ICE	BEV	ICE	BEV	ICE	BEV				
Occupation	**Student**	12	15	3	0	0	0	0	0	15	15	30	4
	Service	92	24	107	29	0	0	35	25	234	78	312	46
	Self-employment	16	35	34	42	55	40	6	0	111	117	228	34
	Others/Driver	8	0	28	0	76	0	0	0	112	0	112	16
												682	
Monthly Income (Rs)	**Up to 20,000/-**	46	19	17	1	86	12	0	0	149	32	181	27
	20,000/- to 50,000/-	50	36	58	27	45	28	17	6	170	97	267	39
	50,000/- to 1,00,000/-	31	17	67	25	0	0	23	19	121	61	182	27
	1,00,000/- and above	1	2	30	18	0	0	1	0	32	20	52	8
												682	
Fuel used	**Petrol**	128	0	103	0	88	0	0	0	319	0	319	47
	Diesel	0	0	69	0	43	0	41	0	153	0	153	22
	Electricity	0	74	0	71	0	40	0	25	0	210	210	31

Number of Persons		Two-Wheeler		Car		Auto Rickshaw		Bus		Total ICE	Total BEV	Grand Total	%
		ICE	BEV	ICE	BEV	ICE	BEV	ICE	BEV				
												682	
Vehicle Owner	**Owner**	120	74	144	70	55	40	26	0	345	184	529	78
	No. Driver	8	0	28	1	76	0	15	25	127	26	153	22
Grand Total												682	

Data Analysis

Impacts of EV adoption in Maharashtra in terms of carbon emission Reduction

Table 5.14 presents the emissions associated with various vehicle types and fuel sources, comparing Internal Combustion Engine (ICE) vehicles with Battery Electric Vehicles (BEVs). For Two-Wheelers, ICE vehicles emit 6042.72 units of total emissions, while BEVs contribute 4001.92 units. Cars show a more significant difference: ICE vehicles emit 35,094.69 units, compared to 22,713.83 units for BEVs. Auto Rickshaws have a similar trend, with ICE vehicles emitting 38,409.76 units versus 10,715.54 units from BEVs. The disparity is most pronounced in Buses, where ICE vehicles produce 638,250.91 units of emissions, whereas BEVs account for 685,539.03 units.

In summary, BEVs generally produce fewer emissions than ICE vehicles across all categories except buses. This reduction is particularly notable in two-wheelers, cars, and auto rickshaws, highlighting the environmental benefits of transitioning to electric vehicles in these segments.

Table 5.14: Life Cycle Emission in CO2 eq Kg

	Two-Wheeler		Car		Auto Rickshaw		Bus	
	ICE	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**
Vehicle Cycle	922.76	817.16	5607.79	4413.86	3591.89	1956.57	70057.88	84748.39
Operation Cycle	4013.3	2628.39	23058.1	12071.29	2703 2.31	7091.07	434127.78	486993.68
Battery Cycle	0.168	612.08	5.69	5857.92	1.515	1311.54	15	88060.56
Fuel Cycle	1066.83	280.41	6026.28	1287.82	7597.86	756.51	113460.24	51954.62
Total Emission	6003.08	4338.04	3469 7.86	23630.89	3822 3.58	11115.69	617660.89	711757.26

Result Summary:

Two-Wheelers, ICE vehicles emit 6003.08 Kg of total emissions, while BEVs contribute 4338.04 Kg. Thus a emission reduction of 1665 Kg. Cars show a more significant difference: ICE vehicles emit 34697.86 units, compared to 23630.89 units for BEVs. An emission reduction of 11067 Kg observed. Auto Rickshaws have a similar trend, with ICE vehicles emitting 38223.58 units versus 11115.69 units from BEVs. An emission reduction of 27108 Kg observed. The disparity is most pronounced in Buses, where ICE vehicles produce 617660.89 units of emissions, whereas BEVs account for 711757.28 units. Thus an emission increase of 94097 Kg observed. In summary, BEVs generally produce fewer emissions than ICE vehicles across all categories except buses. This reduction is particularly notable in two-wheelers, cars, and auto rickshaws, highlighting the environmental benefits of transitioning to electric vehicles in these segments. BEV bus produces more emission than ICE bus as energy that runs bus and manufacture Li-ion battery comes from coal and gas fired power plant. Emission from BEV bus can be reduced significantly if it uses clean energy such as solar, wind, hydro and nuclear energy etc.

5.3. IMPACTS OF EV ADOPTION IN MAHARASHTRA IN TERMS OF FOSSIL FUEL CONSUMPTION

Use Phase

ICE vehicles, including two-wheelers and cars, use significant amounts of petrol, while BEVs do not use petrol at all. For example, two-wheelers and cars have high petrol consumption (1561 LTR and 4033 LTR, respectively), whereas BEVs have zero petrol usage. Diesel consumption is notable for three-wheelers and buses, with ICE vehicles consuming much more diesel compared to BEVs. For instance, buses using ICE consume 237,257 LTR of diesel, whereas BEVs consume only 296.13 LTR. ICE vehicles use coal and natural gas more significantly than BEVs. BEVs have a notable coal and natural gas consumption only in the battery cycle phase.

Manufacturing Cycle

ICE vehicles have substantial diesel consumption during the manufacturing cycle, with cars and buses using high quantities (2483 LTR and 19606 LTR,

respectively). BEVs have lower diesel usage in their manufacturing cycle. ICE vehicles also require more coal in the manufacturing process compared to BEVs. For instance, buses and cars have high coal consumption, while BEVs have lower coal requirements. Both ICE and BEVs use natural gas during manufacturing, but BEVs have a slightly higher consumption compared to ICE vehicles.

Battery Cycle

The battery cycle for BEVs involves significant coal consumption (1054 KG) and minimal diesel use (1.75 LTR). This indicates a reliance on coal for BEV battery production.BEVs also use a notable amount of natural gas during the battery cycle (42.75 CUM), suggesting a significant energy requirement for battery manufacturing.

Life Cycle Fossil Fuel Requirement

ICE vehicles, especially cars, require substantial amounts of petrol over their life cycle, whereas BEVs do not require petrol. ICE vehicles have high diesel requirements throughout their life cycle (e.g., buses with 256,863 LTR), whereas BEVs have significantly lower diesel usage (7643.49 LTR). BEVs use considerably more coal over their life cycle compared to ICE vehicles (e.g., 219,709 KG for BEVs vs. 5,543 KG for ICE vehicles). This indicates that coal is a major resource in BEV lifecycle analysis, primarily due to battery production. The life cycle consumption of natural gas is significantly higher for BEVs compared to ICE vehicles, with BEVs using 8157.48 CUM of natural gas.

The analysis reveals significant differences in emissions and resource usage between Internal Combustion Engine (ICE) vehicles and Battery Electric Vehicles (BEVs). ICE vehicles generally exhibit higher emissions related to petrol, diesel, coal, and natural gas across both their operational and manufacturing phases compared to BEVs. However, BEVs present their own environmental challenges. They have substantial coal and natural gas consumption during battery production and throughout their lifecycle, impacting their overall environmental footprint. While BEVs contribute to a

reduction in the use of fossil fuels like petrol and diesel, the reliance on coal and natural gas for battery manufacturing must be carefully evaluated. This highlights the need for ongoing advancements in BEV production technologies and infrastructure improvements to minimize their environmental impact comprehensively.

Table 5.15: Fossil Fuel Requirement for Various Types of Vehicles

Vehicle Type	Phase	Fuel Type	ICE (Unit)	BEV (Unit)
Two-Wheeler	**Use Phase**	Petrol	1561 LTR	-
		Diesel	866 LTR	1.6 LTR
		Coal	-	961 KG
		Natural Gas	-	39 CUM
	Manufacturing Cycle	Diesel	254 LTR	208 LTR
		Coal	72 KG	58.63 KG
		Natural Gas	2.9 CUM	2.38 CUM
	Battery Cycle	Coal	-	110 KG
		Diesel	-	0.18 LTR
		Natural Gas	-	4.47 CUM
	Life Cycle Fossil Fuel Requirement	Petrol	1561 LTR	-
		Diesel	1120 LTR	209.78 LTR
		Coal	72 KG	1129.63 KG
		Natural Gas	2.9 CUM	45.85 CUM
Three-Wheeler	**Use Phase**	Petrol	5543 LTR	-
		Diesel	10341 LTR	4.31 LTR
		Coal	2592 KG	4412 KG
		Natural Gas	105 CUM	178 CUM
	Manufacturing Cycle	Diesel	960 LTR	745 LTR
		Coal	271 KG	210.6 KG
		Natural Gas	11 CUM	8.54 CUM
	Battery Cycle	Coal	-	236 KG
		Diesel	-	0.39 LTR
		Natural Gas	-	9.57 CUM
	Life Cycle Fossil Fuel	Petrol	5543 LTR	-

Vehicle Type	Phase	Fuel Type	ICE (Unit)	BEV (Unit)
	Requirement			
		Diesel	11301 LTR	749.7 LTR
		Coal	271 KG	3038.6 KG
		Natural Gas	11 CUM	123.11 CUM
Car	**Use Phase**	Petrol	4033 LTR	-
		Diesel	8980 LTR	7.34 LTR
		Coal	4412 KG	177968 KG
		Natural Gas	178 CUM	7218 CUM
	Manufacturing Cycle	Diesel	2483 LTR	3152 LTR
		Coal	702 KG	891 KG
		Natural Gas	28 CUM	36.14 CUM
	Battery Cycle	Coal	-	1054 KG
		Diesel	-	1.75 LTR
		Natural Gas	-	42.75 CUM
	Life Cycle Fossil Fuel Requirement	Petrol	4033 LTR	-
		Diesel	11463 LTR	3161.1 LTR
		Coal	702 KG	6357 KG
		Natural Gas	28 CUM	256.89 CUM
Bus	**Use Phase**	Petrol	-	-
		Diesel	237257 LTR	296.13 LTR
		Coal	177968 KG	-
		Natural Gas	7218 CUM	-
	Manufacturing Cycle	Diesel	19606 LTR	7321 LTR
		Coal	5543 KG	25896 KG
		Natural Gas	225 CUM	296.89 CUM
	Battery Cycle	Coal	-	15845 KG
		Diesel	-	26.36 LTR
		Natural Gas	-	642.59 CUM
	Life Cycle Fossil Fuel Requirement	Petrol	-	-
		Diesel	256863 LTR	7643.49 LTR
		Coal	5543 KG	219709 KG
		Natural Gas	225 CUM	8157.48 CUM

The life cycle fossil fuel requirements for cars and buses reveal notable differences between internal combustion engine (ICE) vehicles and battery electric vehicles (BEVs), as show in the Tabel 5.16. For petrol, ICE cars use 4033 liters, while BEVs use none. However, it can be noticed in the diesel data: ICE cars consume 11463 liters, and while BEVs are listed with 3161 liters of diesel, diesel is consumed in power cycle. Buses show a significant difference in diesel use, with ICE buses consuming 256863 liters, whereas BEVs are listed with 7643.49 liters. In terms of coal, BEVs have a much higher consumption compared to ICE vehicles, indicating that the electricity used for BEVs is largely generated from coal. ICE cars use 702 kg of coal, while BEVs use 6357 kg, and buses use 5543 kg for ICE and 219709 kg for BEVs. Similarly, natural gas consumption is higher for BEVs: ICE cars use 28 cubic meters, while BEVs use 257 cubic meters, with buses consuming 225 cubic meters for ICE and 8157.48 cubic meters for BEVs. This pattern suggests that while BEVs eliminate direct fossil fuel use, their overall fossil fuel consumption can be substantial if the electricity used for charging comes from fossil fuels like coal and natural gas.

Table 5.16: Research Question and Its Findings

Research Question	Research Objectives	Findings
RQ-1 **How environmental concerns, technological developments, and policy measures influence EVs adoption intention in Maharashtra**	RO-1 To analyze factors influencing the adoption intention of electric vehicles in Maharashtra.	RF-1 Environmental concerns, technological developments, and policy measures have a positive influence on EV adoption intention in Maharashtra.
RQ-2 **What are the benefits in terms of emission reduction that will impact the Indian automotive sector due to EV adoption?**	RO-2 To assess the impact of EV adoption in terms of carbon emission reduction in Maharashtra.	RF-2 EV adoption in two-wheeler, three-wheeler and car sector will reduce emission but EV Bus adoption will increase emission.
RQ-3 **What are the effects in terms of fossil fuel consumption that will**	RO-3 To evaluate the impact of EV adoption on fossil fuel	RF-3 EV adoption will reduce fossil fuels of diesel and petrol consumption but it

impact the Indian automotive sector due to EV adoption	consumption in Maharashtra.	will increase fossil fuels of coal and natural gas consumption.

Sensitivity analysis

Sensitivity analysis means how impact factors are affected due to changing values of variables keeping other variables unchanged. In the present case, we can measure how factors such as CO_2 emissions, fossil fuel depletion, etc. are affected by changes in values of variables like power sources, vehicle life, battery life, battery weight, fuel efficiency, etc. While carrying out sensitivity analysis, it has been ensured that the values of only one variable are changed, keeping other variables constant and their effects on various impact factors to be watched (Dhingra et al., 2022). For example, sensitivity analysis is carried out for GHG emissions by ICE vehicles on different fuel efficiency data, and these have been presented through a bar chart. It is observed that CO_2 emissions by BEV two-wheelers, cars, and three-wheelers are lower than the respective ICE vehicles despite reduced CO_2 emissions by ICE vehicles. However, CO_2 emissions by BEV buses are higher than ICE buses. As per the central electricity authority of the Govt. of India, the Indian power mix will improve by RE power up to 55% (presently it is 37%) and coal power up to 32% (presently it is 54%). Thus, sensitivity analysis was carried out with an improved power mix, which is present in bar chart form. It is observed that CO_2 is maximum when power is generated from most carbon-intensive sources, i.e., from coal-fired power plants. GHG emission is minimum when power is produced from the cleanest source, i.e., from RE power. CO_2emissions from all types of BEV vehicles are lower than all types of ICE vehicles.

Table 5.17: Sensitivity Analysis Considering Improvement of Fuel Efficiency Due to Reduction of Fuel Consumption by Introducing Superior Technology

	Two-wheeler (LCA emission in Kg)		Car (LCA emission in Kg)		Three-Wheeler (LCA emission in Kg)		Bus (LCA emission in Kg)	
	ICE	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**
As Per Survey Data	6003.08	4338.04	34697.86	23630.89	38223.58	11115.69	617660.89	711757.28
5% Fuel Efficiency	5789	4338.04	33569	23630.89	36634	11115.69	609174	711757.28
10% Fuel Efficiency	5535	4338.04	32044	23630.89	34858	11115.69	580097	711757.28
15% Fuel Efficiency	5281	4338.04	30518	23630.89	33083	11115.69	551020	711757.28
20% Fuel Efficiency	5028	4338.04	28994	23630.89	31308	11115.69	521944	711757.28

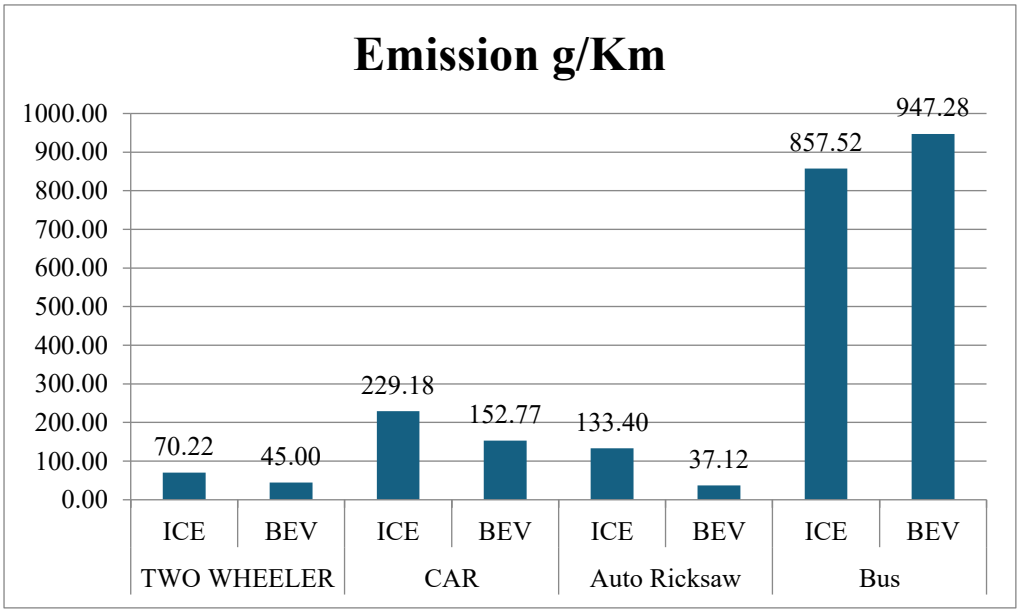
Table 5.18: Sensitivity Analysis Considering Improvement of Power Mix by Decreasing Coal Power and Increasing Renewable Power

	Two-wheeler (LCA emission in Kg)		Three-wheeler (LCA emission in Kg)		Car (LCA emission in Kg)		Bus (LCA emission in Kg)	
	ICE	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**	**ICE**	**BEV**
Present Power Mix	6003.08	4338.04	38223.58	11115.69	34697.86	22713.83	617660.89	711757.28
5% Change in Power Mix	6003.08	3760	38223.58	10047	34697.86	21536	617660.89	640339
10% Change in Power Mix	6003.08	3518	38223.58	9382	34697.86	20358	617660.89	595237
15% Change in Power Mix	6003.08	3276	38223.58	8717	34697.86	19180	617660.89	550087
18% Change in Power Mix	6003.08	3132	38223.58	8322	34697.86	18481	617660.89	523302

Validity

Validity refers to how accurately a method measures what it intends to measure. If research has high validity, that means it produces results corresponding to real properties, characteristics, and variations in the physical or social world. Perfect validity means that there are no measurement errors. The result obtained by different researchers on EV adoption, GHG emission and Fossil fuel requirement for various types of ICE and BEV vehicles. The results observed in our study are in similar lines of EV adoption, GHG emission and Fossil fuel requirement for various types of ICE and BEV vehicles obtained by other researchers across the world. Therefore, validity tested is passed.

Figure 5.3: Carbon Emission for Various type of Vehicles



Reference	CAR (g/Km)		BUS (g/Km)		TWO WHEELER (g/Km)	
	ICE	BEV	ICE	BEV	ICE	BEV
Zeng et al. 2021	200	156				
Ren et al. 2020	223.5	171				
Bieker et al. 2023	250	130			74	54
Encho Zhao 2022			923	1016		
Present study	229.2	152.8	857.5	945.3	70.22	45

5.4. COST BENEFIT ANALYSIS OF ELECTRIC VEHICLE

The **cost-benefit analysis** of **IC engine vehicles** versus **electric vehicles (EVs)** in India reveals that while the **initial purchase cost** of EVs is higher, the **long-term benefits**—including lower operational and maintenance costs, reduced fuel imports, better public health, and environmental advantages—make EVs a more sustainable choice in the long run. Various research articles written by **Rathi, P. et al. (2020),**Srinivasan**et al. (2021)**. Chakrabarti, S. et al. (2019) and Patel, H. et al. (2020) explored the **cost-benefit analysis of EVs** in India, focusing on factors like upfront cost, subsidies, government incentives operating costs, and the economic benefits of reducing fuel imports and improving air quality. In this study it has been tried to assess lifetime savings in monetary terms of **electric vehicles in comparison to IC engine vehicles considering various cost component savings such as** lifetime savings from purchase cost, lifetime savings from fuel, lifetime savings from maintenance, lifetime savings from emission reduction and lifetime savings from government incentives.

Costs of EV Adoption

The study identifies several significant price distinctions between internal combustion engine (ICE) and electric vehicle (EV) models across several categories. First, compared to their internal combustion engine (ICE) equivalents, electric cars and buses are substantially more expensive to buy initially. As a result, both fleet operators and consumers must take this into account. However, in the two-wheeler, three-wheeler, and automobile classes, EVs typically perform better than ICE cars when examining lifetime running costs per kilometre. This benefit is mostly attributable to lower electricity expenditures as well as cheaper maintenance and repair costs. On the other hand, compared to comparable ICE-driven buses, electric buses have a higher lifetime running cost per kilometre, indicating that operational efficiency improvements in this class would not yet be sufficient to cover the initial purchase price. Across all vehicle categories, EVs show a distinct advantage when considering operational costs, which include fuel or energy costs as well as repair/maintenance costs. In these regions, electric vehicles are substantially less expensive, which adds to the overall cost reduction over the course of their lifetime. The financial advantages of switching to electric power are further highlighted by the fact that the lifetime fuel cost of ICE vehicles is significantly

higher than the comparable lifetime electricity cost of comparable EVs. Depending on the kind of vehicle, the cost of the battery accounts for between 9% and 25% of the total operating cost, making it one of the major cost components of EVs. Although this raises the total cost of owning an EV, the significant fuel and maintenance cost reductions, particularly for vehicles, two-wheelers, and three-wheelers, more than make up for it. The need for economies of scale and battery technology developments to further lower EV costs and improve their affordability and competitiveness across all vehicle segments is highlighted by this cost dynamic.

Table 5.19: Lifetime Purchase Cost

Type of Vehicle	Average ex-showroom price in Rs.	Average registration, and taxes in Rs.	Average salvage Value in Rs.	Average subsidy and incentives in Rs.	Lifetime Purchase Cost in Rs.
Internal combustion engine two-wheel vehicles	78672	6456	4720	0	80408
Battery Electric two-wheel vehicles	88646	0	5319	25100	58227
Internal combustion engine three-wheel vehicles	253664	17600	15220	0	256044
Battery Electric three-wheel vehicles	212325	0	12740	51000	148585
Internal combustion engine car	767109	88669	46027	0	809751
Battery Electric car	1423620	0	85417	362375	975828
Internal combustion engine bus	3525986	458378	211559	0	3772805
Battery Electric bus	21440000	0	1286400	2212375	17941225

Table 5.20: Lifetime Operating Cost

Type of Vehicle	Average lifetime fuel/electricity cost in Rs.	Average lifetime repair & maintenance cost in Rs.	Average lifetime insurance cost in Rs.	Average lifetime battery replacement cost in Rs.	Average lifetime emission reduction benefit savings in Rs.	Total Lifetime Operating Cost in Rs.
Internal combustion engine two-wheel vehicles	157133	51563	11780	0	0	220476
Battery Electric two-wheel vehicles	29328	7500	8966	26144	7286	64652
Internal combustion engine three-wheel vehicles	997075	88626	14520	0	0	1100221
Battery Electric three-wheel vehicles	80006	52500	16058	144000	98686	193878
Internal combustion engine car	817504	153052	87592	0	0	1058148
Battery Electric car	134692	64225	137035	330837	44200	622589
Internal combustion engine bus	14235390	750000	779828	0	0	15765218
Battery Electric bus	5478321	375000	1135508	3323040	-168818	10480687

Table 5.21: Lifetime Cost of Vehicle in Maharashtra, India

Type of Vehicle	Lifetime Km. Run	Lifetime Purchase Cost in Rs.	Total Lifetime Operating Cost in Rs.	Total Lifetime Cost in Rs.	Cost Per KM in Rs.
Internal combustion engine two-wheel vehicles	90000	80408	220476	300884	3.34
Battery Electric two-wheel vehicles	90000	58227	64652	122879	1.37
Internal combustion engine three-wheel vehicles	288000	256044	1100221	1356265	4.71
Battery Electric three-wheel vehicles	288000	148585	193878	342463	1.19
Internal combustion engine car	150000	809751	1058148	1867899	12.45
Battery Electric car	150000	975828	622589	1598417	10.66
Internal combustion engine bus	720000	3772805	15765218	19538023	27.14
Battery Electric bus	720000	17941225	10480687	28421912	39.47

Figure 5.4: Percentage Distribution of Cost Components

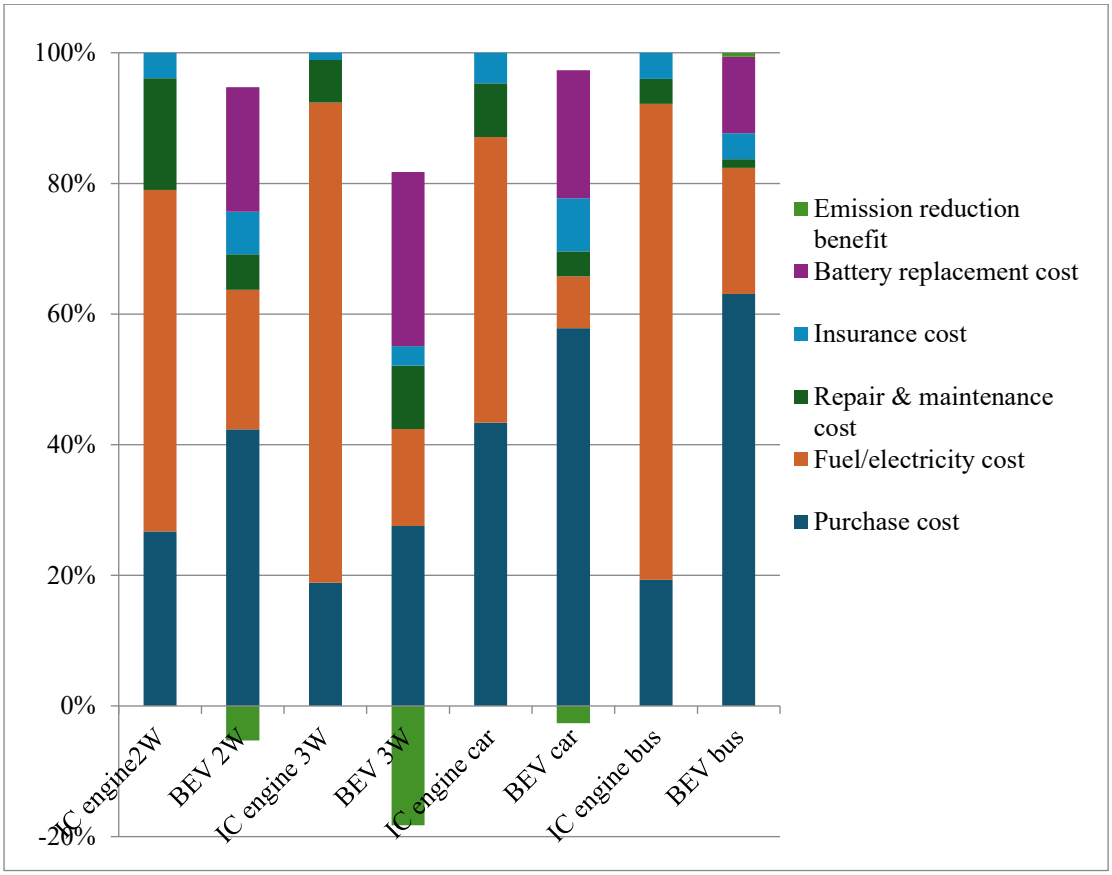


Figure 5.5: Per KM Cost in Rs.

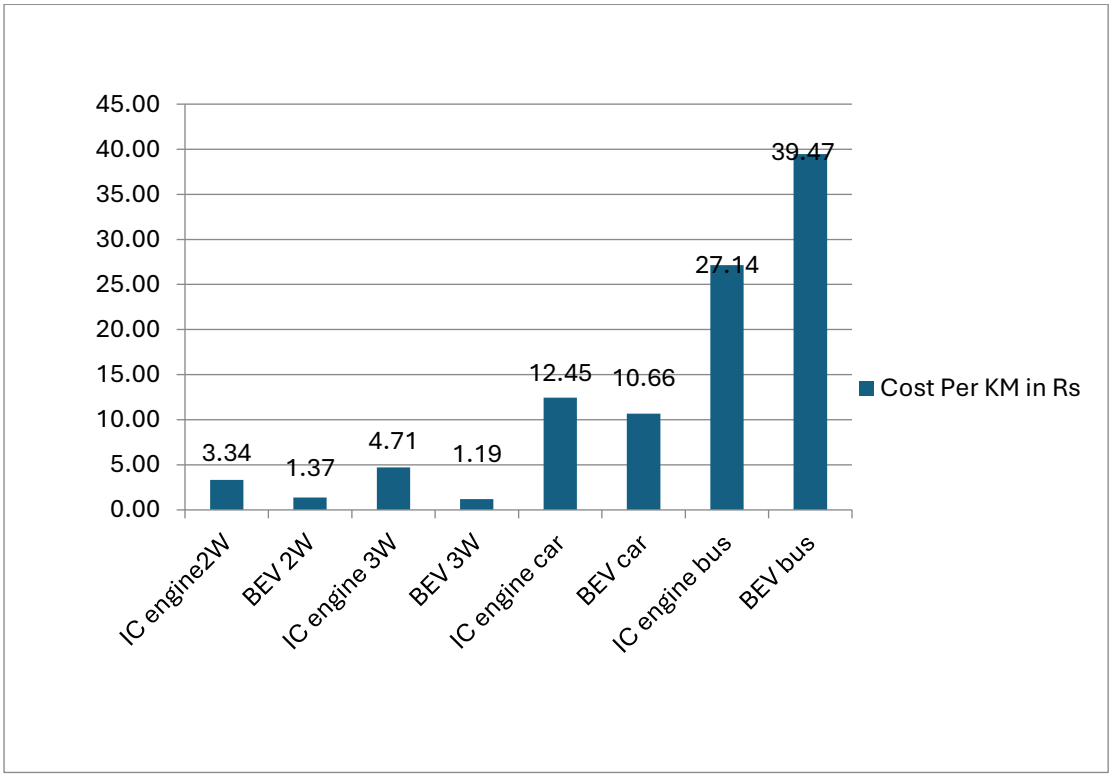
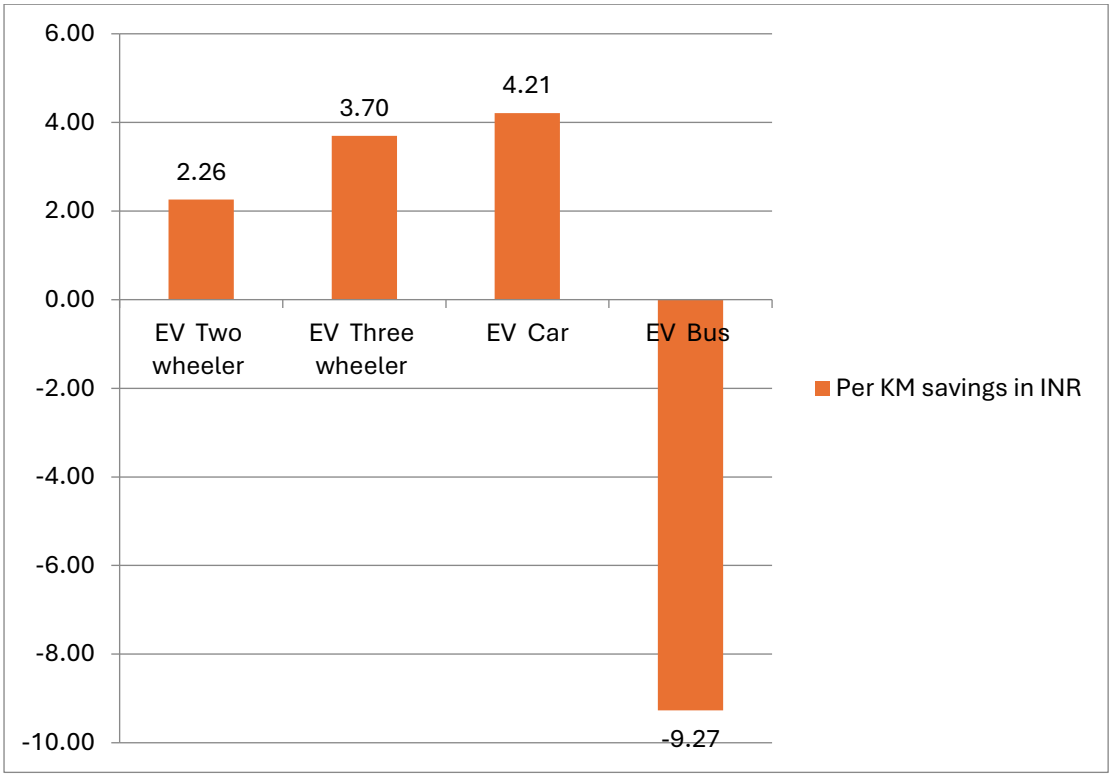


Figure 5.6: Per KM savings in Rs due to EV adoption



Benefits of EV Adoption

The lifetime savings for several battery electric vehicle (BEV) models across a range of price points are compiled in the table. Fuel cost savings (Rs. 127,805) and reduced purchase, repair, and maintenance expenses account for the majority of the Rs. 203,105 lifetime savings. Significant fuel cost reductions (Rs. 917,069) and benefits from subsidies and incentives (Rs. 51,000) account for the largest lifetime savings of Rs. 1,064,984. However, there is a negative impact on repair and maintenance expenditures (Rs. -109,412). Rs. 631,857 in lifetime savings, including Rs. 682,812 in gasoline expenditures and Rs. 362,375 in subsidies and incentives. However, there are significant negative effects from the purchase expenses (Rs. -166,077) and repair/maintenance costs (Rs. -291,453).

Table 5.22: Total Lifetime Savings

Sp: Type of Vehicle	Lifetime savings from purchase cost in Rs.	Lifetime savings from fuel/electricity cost in Rs.	Lifetime savings from repair/maintenance & insurance cost in Rs.	Lifetime savings from subsidy, incentives, registration & taxes in Rs.	Lifetime savings from emission reduction benefit in Rs.	Total Lifetime Savings in Rs.
Battery Electric two-wheel vehicles	22181	127805	20733	25100	7286203105	
Battery Electric three-wheel vehicles	107459	917069	-109412	51000	988681064984	
Battery Electric car	-166077	682812	-291453	362375	44200631857	
Battery Electric bus	-14168420	8757069	-3303720	2212375	-168818-6671514	

It has been found that negative savings for purchase cost of electric car and bus being higher purchase cost in comparison with IC engine car and bus respectively. Similarly negative savings observed in case of repair/maintenance and insurance cost of electric three wheelers, car and bus due to very high battery replacement cost in comparison with IC engine car and bus respectively. High amount of savings found from fuel/electricity cost for all types of electric vehicles. Similarly, a good amount of positive savings observed in case of subsidy and incentives. Positive emission reduction benefit of two-wheeler, three-wheeler and car version of electric vehicle indicated here. Negative emission reduction benefit observed for electric bus due to higher lifetime emission of electric bus than IC engine bus. The study showed positive savings for electric version of two-wheeler, three-wheeler and car whereas negative electric bus is not cost effective when it compared with IC engine bus due to higher purchase cost, higher battery replacement cost and higher emissions.

Chapter 6

Conclusions: Findings and Policy Implications

CHAPTER 6
CONCLUSIONS: FINDINGS AND POLICY IMPLICATIONS

6.1. INTRODUCTION

The adoption of electric vehicles (EVs) in Maharashtra represents a pivotal step towards addressing critical environmental challenges and advancing sustainable development in one of India's most industrialized states. This research has delved into the multifaceted impacts of EV adoption, examining its influence on fossil fuel consumption, emissions, and the socio-economic dynamics of the automotive sector. Despite Maharashtra's status as an automobile hub and the state's proactive policies promoting EV adoption, the pace of transition remains slower than anticipated. Without an increase in EV adoption, Maharashtra risks continuing heavy reliance on fossil fuels, missing out on potential reductions in emissions and air pollution, and failing to meet its sustainability targets. This issue highlights an urgent need to analyze factors influencing EV adoption and to evaluate its environmental, fuel consumption and economic impacts. The study highlights both the opportunities and barriers inherent in this shift, providing a nuanced understanding of how EVs can contribute to a sustainable future.

6.2. SUMMARY FINDINGS

A sample of 390 vehicle owners from Maharashtra was used to explore the impact of environmental factors, technology factors and government policy measures on EV adoption intention in the state. The sample respondents were surveyed via online and face-to-face interview using a pre-tested structured questionnaire. Results from structural equation model reveal that all these factors comprehensively reveal customers EV adoption intention. To assess the impact of EV adoption on emission reduction and fossil fuel consumption, life cycle analysis was applied. Both Primary and secondary data were used to carry out the analysis.

Environment concern factors, technology factors and government policy measures factors comprehensively show customers EV adoption intention in Maharashtra. People believes adopting EV will reduce vehicular emission and stop further damage to air quality and climate at a large. Battery life, battery technology, range, maintenance and overall performance of EV are important factors.

The estimated results show that over their entire life cycle, BEV two-wheeler vehicles emit 34% less CO_2 than ICE two-wheeler vehicles. The BEV three-wheeler vehicle emits 72% less CO_2 than the ICE three-wheeler in its entire life cycle. Similarly, BEV cars emit 35% less CO_2 than ICE cars in their entire life cycle. Whereas a BEV bus emits 7% more CO_2 than an ICE bus in its entire life cycle. ICE two-wheelers, three-wheelers, cars, and buses need petrol to the tune of 1560 L, 5540 L, and 4033 L in their entire lives. ICE Bus does not need petrol. Similarly, ICE two-wheelers, three-wheelers, cars, and buses need diesel to the tune of 1000 L, 10500 L, 8300 L, and 255 K L in their entire lives. BEV two-wheelers, three-wheelers, cars, and buses need coal to the tune of 980 kg, 2750 kg, 5400 kg, and 214 tonnes in their entire lives than ICE two-wheelers, three-wheelers, cars, and buses. The benefit of EV adoption was found as a total lifetime savings of INR 203,105, INR 1,064,984, and INR 631,857 for EV two-wheelers, three-wheelers, and cars, respectively. Currently, there is a lifetime loss of INR 66,715.14 for EV buses. Although BEVs do not consume petrol or diesel, the electrical energy used by BEVs comes from fossil fuel.

EV adoption in two-wheeler, three-wheeler and car sector will reduce emission but EV Bus adoption will increase emission. EV adoption will reduce fossil fuels of diesel and petrol consumption but it will increase fossil fuels of coal and natural gas consumption.

It implies GHG emissions and energy security (petroleum and coal reserves) are not to be overcome with the adoption of BEVs unless electrical energy comes from clean sources such as solar, wind, hydro, sea waves, etc.

6.3. POLICY IMPLICATIONS/SUGGESTIONS

Theoreticale Implications: This study combines the Theory of Planned Behavior and Life Cycle Assessment to explore EV adoption, offering a new framework for future research.

TheeempiricaleImplications: Formula developed for fossil fuel requirements is widely applicable, opening new research opportunities.

PracticaleImplications: The study paves opportunities for local businesses and startups in EV manufacturing, battery recycling, renewable energy integration, EV-friendly infrastructure, such as charging stations and battery-swapping facilities. Research and development grants could be provided to encourage innovation in battery technology and sustainable manufacturing practices.

Implicationseforepolicyemakers: The study will help policymakers to make policy for residential societies and commercial buildings to install free PV panels for all types of charging facilities, create EV-only zones in high-pollution urban areas to encourage cleaner transportation, and create infrastructure development progress, such as dedicated EV parking and charging zones to encourage EV adoption.

Implicationsefor stakeholders: The study findings will guide general public to induct low running cost electric vehicles having lower local air pollution levels that lead to a decrease in respiratory diseases.

ImplicationseforetheeScientificeCommunity: The study encourages researcher to work on recycling and proper disposal of EV batteries to ensure sustainability.

6.4. LIMITATIONS OF THE PRESENT STUDY

The study primarily focuses on Maharashtra, which may limit the generalization of findings to other regions with differing socio-economic, infrastructural, and policy environments. The limited access to real-time, comprehensive, and region-specific data on EV adoption, emissions, and fossil fuel consumption might affect the accuracy of certain analyses and projections. In the power cycle

complete upstream, transportation of feed and transmission lost part emission has been considered for coal power due to its lion share in the power sector. Similar upstream and end of life part emission need to be considered for other type power sources like solar, hydro, nuclear etc. The study relies on secondary data for various sub cycles like vehicle manufacturing, fuel, power and battery which limit the precision of the result of the study.

6.5. FUTURE SCOPE OF RESEARCH

The promotion of EVs in a developing country like India is a challenging task since it involves the financial constraints, resource constraints and the various policies implemented by the government. Thereby, a future study should be conducted that calibrates the practicality of replacing traditional vehicles by electric vehicles. There is very scarcity of primary data in different phases like mining of raw material, transportation of raw material, processing, assembly, transportation and distribution of finished product for power cycle, fuel cycle, vehicle manufacturing and battery cycle in terms of GHG emission and fossil fuel requirement in each phase. Therefore, future research should be conducted so that specifically primary research conducted in these areas and data be made available. The present study also unbars avenues for future research like disposal of used EV batteries, unused IC engines and drivetrain spare parts and their environmental impacts. The study domain pertaining to the Electric Vehicles upstreaming has immense potential which has not been fully explored by the researchers. Thus, enormous potential exists for research in this field.

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LIST OF PUBLICATIONS

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Research Paper 1

Das, P. K., & Bhat, M. Y. (2022). Global electric vehicle adoption: implementation and policy implications for India. *Environmental Science and Pollution Research*, *29*(27), 40612-40622.

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Research Paper 2

Das, P. K., Bhat, M. Y., & Sajith, S. (2024). Life cycle assessment of electric vehicles: a systematic review of literature. *Environmental Science and Pollution Research*, *31*(1), 73-89.

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Research Paper 3

Das, P. K., Bhat, M. Y., Gupta, S., & Gaine, J. A. (2024). Decarbonising transportation: empirical insights into electric vehicles, carbon emissions and energy consumption. *International Journal of Energy Sector Management*, *18*(6), 2059-2085.

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Appendix

APPENDIX-A

EXTENDED TPB MODEL CONSTRUCTS

1. Environmental Concern	
EC1	I think environmental problems are becoming more and more serious in recent years
EC2	I think human beings should live in harmony with nature to achieve sustainable development
EC3	I think we are not doing enough to save scarce natural resource from being used up
EC4	I think individuals have the responsibility to protect the environment
2. Attitude toward adopting an EV	
A1	My adoption of electric vehicle (EV) in the future will result in stopping further damage to the environment
A2	Being able to stop further damage to the air quality and climate at large is good
A3	I think adopting EV to reduce vehicular emission is a smart measure
A4	It feels satisfying for me to adopt EV and reducing vehicular emissions on my part
3. Subjective Norm	
SN1	Most people who are important to me think I should adopt an EV when adopting a vehicle in the near future
SN2	When considering adopting an EV, I wish to do what people who are important to me want me to do (It was deleted in the following analysis)
SN3	If I buy an EV, then most people who are important to me would also buy an EV
SN4	People whose opinions I value would prefer that I adopt an EV when adopting a vehicle in the near future
4. Perceived Behavioral Control	
PBC1	The price of an EV is important to me, and I can afford it when I decide to adopt
PBC2	The maintenance and repair of an EV is important to me when I decide to adopt

PBC3	I can find where to buy an EV if I wanted to
	5. Intention to adopt an EV
AdIn1	I am willing to adopt an EV when adopting a vehicle in the near future
AdIn2	I intend to adopt an EV when adopting a vehicle in the near future
AdIn3	I plan to adopt an EV when adopting a vehicle in the near future
6. Policy and Support	
PS1	How do you perceive the government's role in regulating and ensuring proper infrastructure for electric vehicles?
PS2	How important are government incentives (such as subsidies, tax benefits) in your decision to adopt an electric vehicle?
PS3	To what extent do you believe current government policies (e.g., FAME scheme) are effective in encouraging EV adoption?
7. Technological Factor	
TF1	To what extent do you believe electric vehicles are reliable in terms of battery life and overall performance?
TF2	How do you perceive the maintenance requirements of electric vehicles compared to traditional vehicles?
TF3	Do you think advancements in battery technology and range have made electric vehicles more appealing?
TF4	How do you perceive the maintenance requirements of electric vehicles compared to traditional vehicles?

Appendix-A2

Survey Questionnaire: Primary Data Collection Tool

Dear Respondent,

We appreciate your participation in this household survey. The information you provide will be used solely for academic research and will be kept confidential. This survey is a part of our research study titled "**Electric vehicle adoption and its impact on the environment and fossil fuel consumption in the context of Maharashtra, India".**

Section I: Socio-Demographic Information

Measure	Items
Gender	☐ Male ☐ Female
Age	☐ 18–30 ☐ 30–42 ☐ 42–64 ☐ 64–76
Education	☐ Not educated ☐ High school or below ☐ Intermediate ☐ Under-Graduate ☐ post-graduate or above
Number of Family Members	☐ 0–5 ☐ 5–10 ☐ 10–15 ☐ 15–20
Male Members in Family	☐ 0–5 ☐ 5–10 ☐ 10–15 ☐ 15–20
Female Members in Family	☐ 0–5 ☐ 5–10 ☐ 10–15 ☐ 15–20
Economic Status	☐ BPL (Below Poverty Line) ☐ APL (Above Poverty Line)
Caste	☐ General ☐ OBC ☐ SC ☐ ST ☐ Others

Section II: Environmental Concern

Statement	Response (Tick One)
I think environmental problems are becoming more and more serious in recent years	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I think human beings should live in harmony with nature to achieve sustainable development	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I think we are not doing enough to save scarce natural resources from being used up	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I think individuals have the responsibility to protect the environment	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Section III: Attitude toward adopting an EV

Statement	Response (Tick One)
My adoption of electric vehicle (EV) in the future will result in stopping further damage to the environment	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
Being able to stop further damage to the air quality and climate at large is good	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I think adopting EV to reduce vehicular emission is a smart measure	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
It feels satisfying for me to adopt EV and	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

reduce vehicular emissions on my part	

Section IV: Subjective Norm

Statement	Response (Tick One)
Most people who are important to me think I should adopt an EV when adopting a vehicle in the near future	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
When considering adopting an EV, I wish to do what people who are important to me want me to do (It was deleted in the following analysis)	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
If I buy an EV, then most people who are important to me would also buy an EV	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
People whose opinions I value would prefer that I adopt an EV when adopting a vehicle in the near future	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Section V: Perceived Behavioral Control

Statement	Response (Tick One)
The price of an EV is important to me, and I can afford it when I decide to adopt	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
The maintenance and repair of an EV is important to me	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

when I decide to adopt	
I can find where to buy an EV if I wanted to	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Section VI: Perceived Behavioral Control

Statement	Response (Tick One)
I am willing to adopt an EV when adopting a vehicle in the near future	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I intend to adopt an EV when adopting a vehicle in the near future	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
I plan to adopt an EV when adopting a vehicle in the near future	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Section VII: Policy and Support

Statement	Response (Tick One)
How do you perceive the government's role in regulating and ensuring proper infrastructure for electric vehicles?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
How important are government incentives (such as subsidies, tax benefits) in your decision to adopt an electric vehicle?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
To what extent do you believe current government policies (e.g., FAME scheme) are effective in encouraging EV adoption?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Section VIII: Technological Factor

Statement	Response (Tick One)
To what extent do you believe electric vehicles are reliable in terms of battery life and overall performance?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
How do you perceive the maintenance requirements of electric vehicles compared to traditional vehicles?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
Do you think advancements in battery technology and range have made electric vehicles more appealing?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree
How do you perceive the maintenance requirements of electric vehicles compared to traditional vehicles?	☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Appendix-A3

Survey Questionnaire: Primary Data Collection Tool

EV QUESTIONNAIRE

DIESEL /PETROL BUS (GENERAL QUESTION)

1 Name

2 Gender
   a. Male
   b. Female
   c. Other

3 Age in years
   a. 18-30
   b. 30-40
   c. 40-60
   d. Above 60

4 Education
   a. Up to 10^{th}
   b. Up to 12^{th}
   c. Graduate
   d. Postgraduate & above

5 Occupation
   a. Student
   b. Service
   c. Sefl Employed
   d. Others

6 Address

7	Driving License	Self	Hired Driver	
8	Vehicle Owner	Yes	Driving Vehicles	Other

9 Mobile No.

10 Email ID

11 Type of vehicle using

12 Monthly Income
   a. Less than Rs. 10,000
   b. Rs.10,000 to Rs. 30,000

c. Rs. 30,000 to Rs. 1,00,000.
d. Above Rs. 1,00,000

13 Type of Fuel Used
a. Diesel
b. Petrol
c. CNG

DIESEL /PETROL BUS

1 Do you have any Bus?

a. Yes
b. No

2 If yes, what is the model of your Bus?

3 Fuel Used

a. Petrol
b. Diesel

4 Make (Company of Bus) (TATA, Ashok Leyland, Mahendra etc)

5 What is the mileage of your Bus?

6 Purchase price of your Vehicle.

a. Less than Rs. 15,00,000
b. Rs. 15,00,000 – Rs. 20,00,000
c. Rs. 20,00,000 – Rs. 2500,000
d. Rs. 25,00,000 – Rs. 30,00,000
e. More than Rs. 30,00,000

7 Age of Vehicle

a. More than 15 years
b. 10 years-15 years
c. 5 yars-10 years

d. 2 years-5 years
e. Less than 2 years

8 General use of the vehicle

a. carrying passenger
b. personal purpose
c. business Purpose
d. Others (mention)

9 Average Distance Travelled on Daily Basis

a. Less than 100 kms
b. 100 kms-200 kms
c. 200 kms-300 kms
d. More than 300 kms

10 Average Fuel costs per month

a. Less than Rs.10000
b. Rs.10000 - Rs.20000
c. Rs.20000 – Rs.30000
d. More than Rs. 30000

11 Total servicing cost per year?

a. Less than Rs. 10,000
b. Rs. 10,000 – Rs. 20,000
c. Rs. 20,000 – Rs. 30,000
d. More than Rs. 30,000

12 What sort of issues are you facing with your current electric Bus?

a. High Running Cost
b. Regular Maintenance Needs
c. Frequent Breakdowns
d. Others (Mention)

13 Interested in switching to an electric Bus?

a. Yes
b. No
c. May be

14 Willing to pay a higher purchase price for an electric Bus if monthly ownership costs are significantly lower?

a. Yes
b. No
c. May be

15 From where you get to know about electric Bus?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

16 Do you think there should be electric Bus on the road

a. Yes
b. No

17 Do you know benefits of electric Bus?

a. Yes
b. No

18 Please tick benefits of electric Bus (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

19 Please allot priority number for benefits of electric Bus. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology

g. Easy registration
h. Easy to drive

20 What might be the reason people are not interested in electric Bus according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

21 Where would you prefer to charge your electric vehicle if you were to buy one electric Bus in future.

a. At home
b. At Workplace
c. Charging Station

22 Do you think electric Bus is having more cost than diesel/petrol?

a. Yes
b. No

23 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

ELECTRIC VEHICLE BUS

---

1 Do you have any electric Bus?

a. Yes
b. No

2 If yes, what is the model of your electric Bus?

3 What is the make of your electric Bus (Name of brand)

4 How many units (kwh) of electricity consumed by electric for one Charge?

5 Battery storage

a. Less than 30 kwh
b. 30-60 kwh
c. 60-100 kwh
d. More than 100 kwh

6 Time taken for fully charge the battery

a. less than 2 hours
b. 2- 4 hours
c. 4-6 hours
d. 6-8 hours
e. More than 8 hours

7 Place of charging

a. Bus terminal
b. Public charging system
c. Private charging system

8 KM run in one charge

a. Less than 50 KM
b. 50 KM - 150 KM
c. **1**50 KM – 250 KM
d. 250 Km – 350 KM
e. More than 350 KM

9 KM run per month

a. Less than 3000KM
b. 3000 KM - 5000 KM
c. 5000 KM – 7000 KM
d. 7000 Km –10000 KM
e. More than 10000 KM

10 Cost of power consumption per month

a. Less than Rs 3000
b. Rs 3000 – Rs 10000
c. Rs 10000– Rs 20000
d. Rs 2000 – Rs 30000
e. More than Rs 30000

11 Cost of repair/maintenance per year

a. Less than Rs 5000
b. Rs 5000 – Rs 10000
c. Rs 10000– Rs 20000
d. More than Rs 20000

12 Present life of vehicle

a. Less than one year
b. one year – two years
c. two years – three years
d. three years – five years
e. More than five years

13 Battery change happens

a. Yes
b. No

14 Battery life if changed

a. Less than five years
b. five years – seven years
c. more than seven years

15 Purchase price of your Vehicle.

a. Less than Rs. 50,00,000
b. Rs. 50,00,000 – Rs. 80,00,000
c. Rs. 80,00,000 – Rs. 1,20,00,000

d. Rs. 1,20,00,000 – Rs. 1,50,00,000
e. More than Rs. 1,50,00,000

16 From where you get to know about electric Bus?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

17 Do you think there should be electric Bus on the road

a. Yes
b. No

18 Do you know benefits of electric Bus?

a. Yes
b. No

19 Please tick benefits of electric Bus (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

20 Please allot priority number for benefits of electric Bus. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

21 What might be the reason people are not interested in electric Bus according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

22 Where would you prefer to charge your electric vehicle if you were to buy one electric Bus in future.

a. At home
b. At Workplace
c. Charging Station

23 Do you think electric Bus is having more cost than diesel/petrol?

a. Yes
b. No

24 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

DIESEL /PETROL CAR

---

1 Do you have any Car?

a. Yes
b. No

2 If yes, what is the model of your Car? (Alto, I-10, Scorpio etc)

---

3 Fuel Used

a. Petrol
b. Diesel

4 Make (Company of Car like Maruti, Tata, Mahendra, etc)

5 What is the mileage of your Car?

6. Purchase price of your vehicle?

a. Less than Rs.5 Lac
b. Rs. 5 Lac - Rs. 7 Lac
c. Rs. 7 Lac- Rs. 10 Lac
d. Rs 10 Lac – Rs 15 Lac
e. More than Rs 15 Lac

7 Age of Vehicle

a. More than 15 years
b. 10 years-15 years
c. 5 yars-10 years
d. 2 years-5 years
e. Less than 2 years

8 General use of the vehicle

a. carrying passenger
b. personal purpose
c. business Purpose
d. Others (mention)

9 Average Distance Travelled on Daily Basis

a. Less than 20 kms
b. 20 kms-50 kms
c. 50 kms-100 kms
d. More than 100 kms

10 Average Fuel costs per month

a. Less than Rs.1000
b. Rs.1000 - Rs.3000
c. Rs.3000 – Rs.5000
d. More than Rs.5000

11 Total servicing cost per year?

a. Less than Rs. 5000
b. Rs. 5000 – Rs. 10,000
c. Rs. 10,000 – Rs. 15,000
d. More than Rs. 15,000

12 What sort of issues are you facing with your current vehicle?

a. High Running Cost
b. Regular Maintenance Needs
c. Frequent Breakdowns
d. Others (Mention)

13 Interested in switching to an electric vehicle?

a. Yes
b. No
c. May be
d. Have some reservations on electric vehicles?

14 Willing to pay a higher purchase price for an electric vehicle if monthly ownership costs are significantly lower?

a. Yes
b. No
c. May be

15 From where do you get to know about electric Car?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

16 Do you think there should be electric Car on the road

a. Yes
b. No

17 Do you know benefits of electric Car?

a. Yes
b. No

18 Please tick benefits of electric Car (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration

Easy to drive

19 Please allot priority number for benefits of electric Car. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

20 What might be the reason people are not interested in electric Car according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

21 Where would you prefer to charge your electric Car if you were to buy one electric Car in future.

a. At home
b. At Workplace
c. Charging Station

22 Do you think electric Car is having more cost than diesel/petrol?

a. Yes
b. No

23 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

ELECTRIC CAR

1 Do you have any electric Car?

a. Yes
b. No

2 If yes, what is the model of your electric Car?

3 What is the make of your electric Car (Name of brand)

4 Battery capacity

a. 12 V 70 AH
b. 2 V 100 AH
c. 12 V 120 AH
d. more than 12 V 120 AH

5 Time taken for fully charge the battery

a. less than 2 hours
b. 2- 4 hours
c. 4-6 hours
d. 6-8 hours
e. more than 8 hours

6 Place of charging

a. Home
b. Office
c. Public charging system
d. Private charging system

7 KM run in one charge

a. Less than 200 KM
b. 200 KM - 250 KM
c. 250 KM – 300 KM
d. 300 Km – 350 KM
e. More than 350 KM

8 How many units (kwh) of electricity consumed by EV for one Charge?

9 KM run per month

a. Less than 3000KM
b. 3000 KM - 5000 KM

c. 5000 KM – 7000 KM
d. 7000 Km – 10000 KM
e. More than 10000 KM

10 Cost of power consumption per month

a. Less than Rs 1000
b. Rs 1000 – Rs 2000
c. Rs 2000– Rs 4000
d. Rs 4000 – Rs 6000
e. More than Rs 6000

11 Cost of repair/maintenance per year

a. Less than Rs 3000
b. Rs 3000 – Rs 5000
c. Rs 5000– Rs 10000
d. More than Rs 10000

12 Present life of vehicle

a. Less than one year
b. one year – two years
c. two years – three years
d. three years – five years e) More than five years

13 Battery change happens

a. Yes
b. No

14 Battery life if changed

a. less than five years
b. five years – seven years
c. more than seven years

15 From where you get to know about electric Car?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

16 Do you think there should be electric Car on the road

a. Yes
b. No

17 Do you know benefits of electric Car?

a. Yes
b. No

18 Please tick benefits of electric Car (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

19 Please allot priority number for benefits of electric Car. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

20 What might be the reason people are not interested in electric Car according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

21 Where would you prefer to charge your electric vehicle if you were to buy one electric Car in future.

a. At home
b. At Workplace
c. Charging Station

22 Do you think electric Car is having more cost than Deisel/petrol?

a. Yes
b. No

23 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

DIESEL /PETROL THREE-WHEELER

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1 Do you have any three-wheeler?

a. Yes
b. No

2 If yes, what is the model of your three-wheeler?

3 Fuel Used

a. Petrol
b. Diesel

---

4 Make (Company of three-wheeler)

5 What is the mileage of your three-wheeler?

6 Purchase price of your Vehicle.

a. Less than Rs. 50000
b. Rs. 50,000 – Rs. 1,00,000
c. Rs. 1,00,000 – Rs. 1,50,000
d. Rs. 1,50,000 – Rs. 2,00,000
e. More than Rs. 2,00,000

7 Age of Vehicle

a. More than 15 years
b. 10 years-15 years
c. 5 yars-10 years
d. 2 years-5 years
e. Less than 2 years

8 General use of the vehicle

a. carrying passenger
b. personal purpose
c. business Purpose
d. Others (mention)

9 Average Distance Travelled on Daily Basis

a. Less than 20 kms
b. 20 kms-50 kms
c. 50 kms-100 kms
d. More than 100 kms

10 Average Fuel costs per month

a. Less than Rs.1000
b. Rs.1000 - Rs.3000
c. Rs.3000 – Rs.5000
d. More than Rs.5000

11 Total servicing cost per year?

a. Less than Rs. 3000

b. Rs. 3000 – Rs. 5,000
c. Rs. 5,000 – Rs.7,000
d. More than Rs. 7,000

12 What sort of issues are you facing with your current vehicle?

a. High Running Cost
b. Regular Maintenance Needs
c. Frequent Breakdowns
d. Others (Mention)

13 Interested in switching to an electric three-wheeler?

a. Yes
b. No
c. May be

14 Willing to pay a higher purchase price for an electric three-wheeler if monthly ownership costs are significantly lower?

a. Yes
b. No
c. May be

15 From where you get to know about electric three-wheeler?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

16 Do you think there should be electric three-wheeler on the road

a. Yes
b. No

17 Do you know benefits of electric three-wheeler?

a. Yes
b. No

18 Please tick benefits of electric three-wheeler (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

19 Please allot priority number for benefits of electric three-wheeler. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives
f. New Technology
g. Easy registration
h. Easy to drive

20 What might be the reason people are not interested in electric three-wheeler according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

21 Where would you prefer to charge your electric three-wheeler if you were to buy one electric three-wheeler in future.

a. At home
b. At Workplace
c. Charging Station

22 Do you think electric three-wheeler is having more cost than diesel/petrol?

a. Yes
b. No

23 How many charging station you have observed in your area?

g. One
h. Two
i. Three
j. Four
k. More
l. No Charging Station

ELECTRIC THREE-WHEELER

1 Do you have any electric (Battery) three-wheeler?

a. Yes
b. No

2 If yes, what is the model of your electric (Battery) three-wheeler?

3 What is the make of your electric (Battery) three-wheeler (Name of brand)

4 How many units (kwh) of electricity consumed by electric three-wheeler for one Charge?

5 Battery capacity

a. 12 V 70 AH
b. 12 V 100 AH
c. 12 V 120 AH
d. More than 12 V 120 AH

*6 Time taken for fully charge the battery

a. Less than 2 hours
b. 2- 4 hours
c. 4-6 hours
d. 6-8 hours
e. More than 8 hours

7 Place of charging

a. Home
b. Office
c. Public charging system
d. Private charging system

8 KM run in one charge

a. Less than 200 KM
b. 200 KM - 250 KM
c. 250 KM – 300 KM
d. 300 Km – 350 KM
e. More than 350 KM

9 KM run per month

a. Less than 3000 KM
b. 3000 KM - 5000 KM
c. 5000 KM – 7000 KM
d. 7000 Km – 10000 KM
e. More than 10000 KM

10 Cost of power consumption per month

a. Less than Rs 1000

b. Rs 1000 – Rs 2000
c. Rs 2000– Rs 4000
d. Rs 4000 – Rs 6000
e. More than Rs 6000

11 Cost of repair/maintenance per year

a. Less than Rs 3000
b. Rs 3000 – Rs 5000
c. Rs 5000– Rs 10000
d. More than Rs 10000

12 Present life of vehicle

a. Less than one year
b. one year – two years
c. two years – three years
d. three years – five years
e. More than five years

13 Battery change happens

a. Yes
b. No

14 Battery life if changed

a. less than five years
b. five years – seven years
c. more than seven years

15 Purchase price of your Vehicle.

a. Less than Rs. 50000
b. Rs. 50,000 – Rs. 1,00,000
c. Rs. 1,00,000 – Rs. 1,50,000
d. Rs. 1,50,000 – Rs. 2,00,000
e. More than Rs. 2,00,000

16 From where you get to know about electric three-wheeler?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

17 Do you think there should be electric three-wheeler on the road

a. Yes
b. No

18 Do you know benefits of electric three-wheeler?

a. Yes
b. No

19 Please tick benefits of electric three-wheeler (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives

20 Please allot priority number for benefits of electric three-wheeler. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives

21 What might be the reason people are not interested in electric three-wheeler according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance

g. Range (One change how many KM run)

22 Where would you prefer to charge your electric three-wheeler if you were to buy one electric three-wheeler in future.

a. At home
b. At Workplace
c. Charging Station

23 Do you think electric three-wheeler is having more cost than diesel/petrol?

a. Yes
b. No

24 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

DIESEL/PETROL TWO-WHEELER

1 Type of Two-Wheeler

a. Bike
b. Scooter

2 Fuel Used

a. Petrol
b. Diesel

3 Model of Two-Wheeler

- (Splendor, Apache and Activa etc.)

4 Make (Company of Two-Wheeler, like Hero, Bajaj etc)

5 Mileage of Vehicle used

6 Average Distance Travelled on Daily Basis?

a. Less than 20 kms
b. 20 kms-50 kms
c. 50 kms-100 kms
d. More than 100 kms

7 Average Fuel costs per month?

a. Less than Rs.1000
b. Rs.1000 - Rs.3000
c. Rs.3000 - Rs. 5000
d. More than Rs.5000

8 Total servicing cost per year?

a. Less than Rs.3000
b. Rs.3000 - Rs.5000
c. Rs.5000 - Rs. 7000
d. More than Rs.7000

9 What sort of issues are you facing with your current vehicle?

a. High Running Cost
b. Regular Maintenance Needs
c. Frequent Breakdowns
d. Others (Mention)

10 Interested in switching to an EV?

a. Yes
b. No
c. Maybe

11 Are you aware about electric scooter /e-bike?

a. Yes
b. No

12 From where you get to know about e-scooter /e-bike?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

13 Do you think there should be e-scooter /e-bike on the road

a. Yes
b. No

14 Do you know benefits of e-scooter /e-bike?

a. Yes
b. No

15 Please tick benefits of e-scooter /e-bike (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy

d. Status Symbol
e. Govt Subsidy and incentives

16 Please allot priority number for benefits of e-scooter /e-bike. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives

17 What might be the reason people are not interested in electric scooter/e-bike according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

18 Are you interested to buy in electric two-wheeler?

a. Yes
b. No
c. May be

19 Are you interested in owing/converting your scooter into e-scooter /e-bike?

a. Yes
b. No
c. May be

20 Where would you prefer to charge your electric vehicle if you were to buy one e-scooter /e-bike in future.

a. At home
b. At Workplace
c. Charging Station

21 Do you think e-scooter/e-bike is having more cost than diesel/petrol scooter/bike?

a. Yes
b. No

22 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

ELECTRIC TWO-WHEELER

1 Do you have any electric two-wheeler?

a. Yes
b. No

2 If yes, what is the model of your two-wheeler?

3 What is the make of your e-two-wheeler (Name of brand like Hero, Honda, Bajaj etc)

4 How many units of electricity required for one complete charge?

5 Amount in Rs of electricity bill in one month for charging electric vehicle?

6 Battery capacity

a. 48 V 20 AH
b. 48 V 24 AH
c. 48 V 30 AH
d. Less than 48 V 20 AH

7 Time taken for fully charge the battery

a. less than 3 hours
b. 3 hours
c. 4 hours
d. 5 hours
e. more than 5 hours

8 Place of charging?

a. Home
b. Office
c. Public charging system
d. Private charging system

9 KM run in one charge?

a. Less than 40 KM
b. 40 KM - 50 KM
c. 50 KM – 60 KM
d. 60 KM – 70 KM
e. More than 70 KM

10 KM run per month?

a. Less than 3000KM
b. 3000 KM - 5000 KM
c. 5000 KM – 7000 KM
d. 7000 KM – 9000 KM
e. More than 9000 KM

11 Cost of power consumption per month?

a. Less than Rs 200
b. Rs 200 – Rs 400
c. Rs 400– Rs 600
d. Rs 600 – Rs 800
e. More than Rs 800

12 Cost of repair/maintenance per year?

a. Less than Rs 500
b. Rs 500 – Rs 1000
c. Rs 1000– Rs 1500
d. Rs 1500 – Rs 2000
e. More than Rs 2000

13 Present life of vehicle?

a. Less than one year

b. one year – two years
c. two years – three years
d. three years – five years
e. More than five years

14 Battery change happens.

a. Yes
b. No

15 Battery life if changed?

a. Less than five years
b. Five years – seven years
c. More than seven years

16 Purchase price of your vehicle.

a. Less than Rs.50,000
b. Rs. 50,000 - Rs. 75,000
c. Rs. 75,000- Rs. 1Lakh
d. More than Rs. 1Lakh

17 From where you get to know about e-scooter/e-bike?

a. Friends or relatives
b. TV or New Papers
c. Dealer
d. Agent

18 Do you think there should be e-scooter/e-bike on the road

a. Yes
b. No

19 Do you know benefits of e-scooter/e-bike?

a. Yes
b. No

20 Please tick benefits of e-scooter/e-bike (Can be tick one or more or all)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives

21 Please allot priority number for benefits of e-scooter/e-bike. (Most priority to be allotted 1 and least priority to be allotted 8)

a. Environment friendly as no gas emitted from exhaust.
b. Charging Cost less than Petrol/Diesel
c. Less Noisy
d. Status Symbol
e. Govt Subsidy and incentives

22 What might be the reason people are not interested in electric scooter/bike according to you?

a. Awareness
b. Initial Cost
c. Charging Station
d. Battery life
e. Battery Cost
f. Maintenance
g. Range (One change how many KM run)

23 Where would you prefer to charge your electric vehicle if you were to buy one e-scooter/e-bike in future.

a. At home
b. At Workplace
c. Charging Station

24 Do you think e-scooter/e-bike is having more cost than diesel/petrol scooter/bike?

a. Yes
b. No

25 How many charging station you have observed in your area?

a. One
b. Two
c. Three
d. Four
e. More
f. No Charging Station

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