Chapter 1

Introduction, motivation and challenges

1.1. Introduction

The world today is at the crossroads of globalisation, technicalities, and industrialisation. Technology has entered every aspect of our lives. However, the adverse effects of the industrial revolution have had substantial effects on the environment. The impact of current technology emissions, as well as pollution, on the health of the planet is now a growing concern for all, particularly those involved in the automotive industry. Internal combustion engines (ICEs), which are widely used in cars and two-wheelers, pose a major threat to both the environment and human life. Since transportation is a significant source of global pollution, the search for solutions has reignited the interest for electric vehicles (EVs). The vehicle industry is at the cusp of transition where EVs have begun to gain near-universal acceptance over conventional vehicles. The shift to EVs is an immediate measure that needs to be taken in order to build ourselves a green environment. EVs are regarded as the cars of the future in order to address oil dependence and environmental issues. It has been reported that the average annual reduction in carbon dioxide (CO_2) emissions caused by one single electric vehicle on the road is 1.5 million grams [1]. The use of EVs has almost become necessary in highly polluted countries like India. The EV industry in India has, however, gained notable traction in recent years. The rise has undoubtedly been slower than in some other countries, but there are indications of change in this trend. Manufacturing giants like Tata Motors and Mahindra & Mahindra have introduced EV models in the market, which are seen to be slowing acquiring acceptance amongst the masses. The Economic Survey 2023 forecasts that India's domestic EV market will experience a compound annual growth rate (CAGR) of 49 % between 2022 and 2030, with a prediction of 10 million units to be sold annually by 2030. Additionally, it is anticipated that the EV industry will generate an approximate of 50 million employoment opportunities by 2030 [2]. Although the concept of EV is not new, its current expansion has been somewhat constrained. This is due to a number of fundamental factors, including cost, charging time, and driving range. Range anxiety is frequently brought on by the limited range of an electric car and is regarded as one of the major factors influencing EV acceptance to this day. In order to reduce greenhouse gas emissions globally, increasing the proportion of renewable energy utilised in the transportation sector is considered a key step. Even though they still have issues with high battery costs and limited range, EVs have long been considered a solution if the electricity is generated from renewable sources. However, because fossil fuels are used to produce it, electric energy is not a completely clean energy source. Therefore, energy conservation, as well as its minimization in the case of EVs, is a challenge that is currently being researched. This research is broadly based on minimising energy usage in electric vehicles. An effort has been made to showcase efficient energy usage by introducing and studying the concept of "Eco-routing" as a solution for the aforementioned problem. Eco-routing of electric vehicles is a considerably new roadway navigation concept. It is a technique that employs the Global Positioning System (GPS) and identifies a route that will consume the least amount of energy while traversing from one point to another [3]. It is marketed as a solution for drivers to improve transportation efficiency and, hence, reduce energy usage. According to reports, this system increases the driving range of electric vehicles by at least 10% and has the potential to reduce their energy consumption by up to 51% [3–4]. This research shall mainly be focused on the identification of major factors that affect energy consumption in EVs and the estimation of energy usage during a trip to determine the most energy-efficient route and thereby facilitate eco-routing navigation in battery electric vehicles (BEVs).

Interest in electric vehicles has skyrocketed because of the increased emphasis on environmental issues and sustainable energy. The principal motive of this work is to provide a solution that can diminish the prolific rise in pollution in the environment. Automobile pollution and global warming are significant impediments to a green environment, so a shift to EVs is necessary. The drivetrains of these vehicles can operate at quite high efficiencies, demonstrating their significant potential to reduce energy demand, in contrast to internal combustion (IC) engines, which use only about 20% of the total energy to move the vehicle [5]. Although adorned with multiple merits, EVs have their share of demerits too. The production of EVs involves various factors that contribute to the current increase in pollution [6]. The initial cost of EVs is quite high. Moreover, they will not be a fully sustainable option until the electricity they use comes from renewable energy sources. For consumers planning to switch to electric vehicles, the cost and constrained driving ranges are outweighed by the benefits of pinning electric vehicles to renewable energy sources. Energy-efficient driving has been realised as a viable challenge, and as a solution, the concept of eco-routing has been introduced. Eco-routing guarantees less fuel use, which will lower the carbon footprint of a fossil fuel-powered vehicle. However, in the case of EVs, in addition to reducing energy demand, it offers ways to reduce "range anxiety" by helping the driver choose a route that will allow the remaining range to be covered by the available charge in the battery [4, 7]. The most important factor in designing an optimal eco-routing navigation system is probably energy consumption. Energy usage is influenced directly or indirectly by a wide range of factors, including the environment, road data, and stochastic factors. Conventional vehicle energy consumption models have not taken into account the change in road elevation, which is believed to significantly influence energy consumption of EVs. Other factors include operating conditions, auxiliary power draws, driving style, and vehicle parameters.

1.1.1. Electric vehicle

An electric vehicle is an automobile that uses one or more electric or traction motors for its propulsion [8]. It differs from conventional fuel powered vehicles in the fact that EVs are generally powered by a battery source located onboard the vehicle. Fig. 1.1 illustrates the primary difference between an EV and an Internal Combustion Engine Vehicle (ICEV). A generator may also be used to convert fuel into electricity for the electric vehicle's propulsion. The utilised motors generate instantaneous torque, resulting in powerful and seamless acceleration [8]. EVs were first developed in the middle of the 19th century, when electricity was favoured for vehicle propulsion. In comparison to their gasoline counterparts; they were easier to operate and offered more comfort [9]. With the passage of time, advancements in ICEs and gasoline-powered vehicle research caused a decline in the use of electric motor vehicles. Since then, the ICE has been the dominant method of propulsion for motor vehicles, although electric power has maintained its dominance in railways and smaller vehicles [10]. In India, pollution has almost reached its zenith, and a shift to EVs seems like the ultimate need of the hour. The Indian EV market, however, is still in its infancy. The government has, however, adopted various schemes and policies for the same. The Faster Adoption and

Manufacturing of (Hybrid and) Electric Vehicles in India (FAME India) Scheme was launched in 2015 to promote and escalate manufacturing of electric and vehicles and ensure its sustainable growth [11]. By 2030, India intends to make a significant switch to electric vehicles, following the National Electric Mobility Mission Plan (NEMMP) [12]. The idea of an all-electric passenger car market in India by 2030, with system greening serving as the link, has been dubbed the "LED moment of transportation" [13]. Electric vehicles are substantially quieter than conventional ICEVs, but their absence of tailpipe emissions plays a significant role in reducing local air pollution. EVs reduce our reliance on hydrocarbons and are less expensive to operate, which reduces our carbon footprint significantly. Because of the expensive cost of batteries, the majority of EVs have a limited range. In addition, the price of purchase is somewhat higher than that of conventional vehicles. EV drivers frequently dread that their batteries will run out before they reach their destination. This apprehension or worry is known as "range anxiety." A substantial quantity of research has been conducted in an effort to reduce energy consumption as a result of rising awareness of the harmful effects of emissions. EVs are also referred to as plug-in electric vehicles, and they can be primarily categorised as either all-electric vehicles (AEVs) or plug-in hybrid electric vehicles (PHEVs). AEVs consist of both battery-electric vehicles and fuel-cell electric vehicles. EVs are capable of being fueled by the electrical grid or battery sources. The concept of regenerative braking, that is, energy generated when an EV's brakes are engaged, has also been applied to charging EVs. The majority of AEVs have all-electric ranges between 80 and 100 miles, while a few luxury models have ranges up to 250 miles [10]. Typically, PHEVs use both electric and internal combustion engine (ICE) propulsion. They typically operate on electricity for shorter distances and can transition to an internal combustion engine when the battery is depleted. Since PHEVs operate on electricity and gasoline over greater distances, their aggregate energy efficiency is superior to that of conventional vehicles. Other sources of energy for PHEVs include alternative fuels, fuel cells, biofuels, etc. [10]. Some PHEVs are also referred to as extended-range electric vehicles (EREVs).

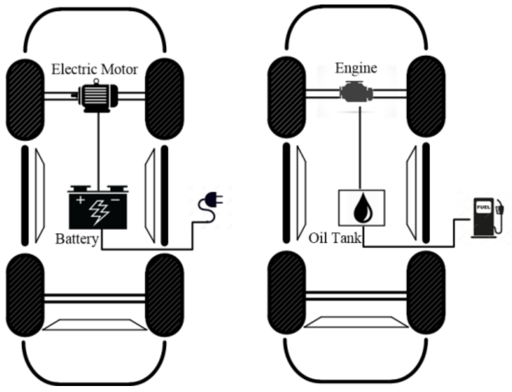

Fig.1. 1 A schematic illustrating the difference between (a) an electric vehicle and (b) internal combustion engine (ICE) vehicle

1.1.2. Advantages of electric vehicles

i. Electric Vehicles have a number of advantages over their internal combustion engine counterparts. Some merits include the following:
ii. EVs do not emit tailpipe pollutants, thereby reducing the production of harmful greenhouse gases that harm the environment.
iii. They are energy-efficient. Electric vehicles are capable of converting over 77% of the received energy from the grid into power to propel the wheels [14].
iv. EVs can prove helpful in driving renewable energy forward through improved battery technology and the successful implementation of vehicle-to-grid systems.
v. EVs can be a true green alternative if the power plants used in their production use energy from renewable sources like solar or wind.
vi. They assist in reducing oil dependence.
vii. The cost of operation and maintenance is lower for EVs.
viii. They cause very little noise pollution, as they are quite silent when in operation and also minimise the overall carbon footprint.
ix. Electric motors provide quiet, smooth operation and acceleration that is stronger than that of ICEVs.
x. They can generate electricity from braking. This concept is called regenerative braking, where it converts the kinetic energy created during braking into electrical energy that is used to charge the high-voltage battery. Additionally,

regenerative braking slows down the vehicle, enhancing the effectiveness of traditional brakes.

xi. Motor efficiency is higher as compared to ICEVs.

1.1.3. Eco-routing navigation in electric vehicles

Eco-routing is a navigation approach for automobiles that aids in the determination of a route and minimises vehicle energy consumption when compared to traditional routing methods. It is based on the postulation that longer travel times can be bartered for lower consumption [15]. It has been observed that eco-routes generally lengthen the travel time, and at times, drivers are compelled to oblige with this lengthening in order to keep the route operational. It entails optimising the energy to be consumed, as well as any emissions, for all different route options to a specific vehicle's destination prior to selecting any route option. Though significant research on the eco-routing of conventional vehicles exists, incorporating novel eco-routing features in EVs opens up new avenues. Such a system could be designed to take map data and convert it to route data, such as road grade, speed, and velocity. First, all possible routes between a source and destination pair are considered. A developed model is then used to estimate the travel time and energy consumption for each route. Based on the model results, the route with the highest energy efficiency is chosen as the eco-route. Eco-routing has emerged as one of the improved concepts aimed at reducing energy consumption and thus operational costs in EVs. Eco-routing takes into account a number of variables, including real-time traffic data, the weight of the car, weather conditions, and location-specific characteristics like road type, road grade, and speed limits, in addition to the distance. Energy consumption in EVs can be successfully reduced with the use of an eco-routing system that is properly implemented. Eco-routing in EVs can assist drivers in choosing a route where the destination can be reached with the available charge in the battery. There are systems available that can achieve an eco-route by using an on-board GPS navigation device that computes the minimum energy route based on a variety of departure conditions. Real-time methods are based on the availability of online information and result in more optimed routing, but there is involvement of complex algorithms in the process [3]. The eco-routing concept also has several limiting assumptions. For example, all vehicles travelling between a source and a destination using the same eco-route will cause more congestion and thus consume more time and energy. Similar to this, other paths will probably have shorter travel times if all vehicles choose the shortest route due to congestion. The presumption that some drivers may prioritise energy efficiency while others may prefer to cut down on travel time is a ravelling factor. When creating an effective eco-routing system, consideration must also be given to the needs and behaviours of the drivers. When there are several alternate paths to the same destination, these systems can estimate the most energy-efficient path during a manoeuvre. It is crucial to mention here that the design of an eco-routing system includes all major constituents responsible for energy consumption or loss in a vehicle and predicts a path for travel that saves the most energy but may not always be the shortest. It is important to note here that the design of an eco-routing system takes into account all major constituents responsible for energy consumption or loss in a vehicle and predicts a path for travel that saves the most energy but may not always be the shortest. However, an eco-route is essential for EV users because it significantly contributes to EV range extension.

Eco-routing systems can be classified as stand-alone or route based and co-operative. Co-operative systems share traffic and energy consumption data with vehicles in the same class. Data from all vehicles are collected and updated to a main controller system from which all vehicles on the same route can be benefitted. The number of vehicles using the navigation system then becomes crucial because the more precise the eco-routing information, the greater the number of vehicles in the network. Route-based systems, on the other hand, collect data while a specific vehicle is in motion. It is specific to one vehicle and analyses information of the route based on specifications of that vehicle only. Inputting route information to vehicle controllers is another application for eco-routing. With knowledge of upcoming traffic or terrain, vehicle control strategies might become even more intelligent. A comparison of the calculated energy consumption results for two control strategies in a Plug-in Hybrid EV (PHEV) model was done by Zhang et al. in 2010 [16]. They mainly concentrated on terrain data and battery energy storage in various terrains. A parallel PHEV driving in hilly terrain was found to have a 1-4% increase in fuel efficiency. All prevalent eco-routing processes are time-dependent, which is dependent on the distance between a requested source and destination. The majority is based on traffic updates. When a routing decision is made, the system continuously recalculates to account for any new traffic data and notifies the driver if another route appears to be more efficient.

1.1.4. Energy consumption in electric vehicles

The most crucial element in the development of an ideal eco-routing navigation system is probably energy usage. EVs can function at over 80% efficiency, thus reducing energy demand [17]. Numerous variables, such as stochastic elements, weather conditions, and road information, all have an impact on energy use, either directly or indirectly. It has been noted that traditional vehicle energy consumption models have ignored changes in road elevation, which may be a key factor in the analysis of energy consumption. There have been a number of publications that advance the development of an effective eco-routing navigation system and discuss energy minimization in an EV. When estimating an EV’s range, a good energy consumption model is essential. Estimation of EV energy usage and range is the foremost step in building an eco-routing system. An energy consumption model generally includes a road load model, a battery model, a powertrain loss model, and regenerative braking from the vehicle wheel to the battery [7]. According to the literature, the majority of navigation systems' models are based exclusively on distance. However, in addition to distance, other factors also have a significant impact on how much energy an EV uses.

The energy usage and range of EVs are affected by a number of factors. All automobiles, including EVs, exhibit reduced efficiency in certain conditions. The range of EVs can be effectively improved by employing simple and cost effective energy consumption models. The energy consumption of EVs is known to be affected by a variety of different several factors. The major contributing factors include vehicle speed and acceleration, vehicle mass and road load, or tractive effort, tyre pressure, vehicle specific parameters, such as coefficient of drag and rolling resistance, driving cycle, road gradients as well as battery dependent factors. Energy usage of an EV directly depends on its speed. The electric motor works harder when the speed is high, which is the cause of this. As a result, driving at the ideal pace will be more energy-efficient. The type of road is also an important contributing factor. The kind and texture of the road will affect the way a vehicle behaves. The tyre pressure is another element that substantially impacts the driving range. The range of an EV can be negatively impacted by energy-inefficient tyre manufacture, inadequate inflation, and other factors [18]. According to research, the majority of energy estimation methods do not account for road gradients in their computations. In this research work, an analysis of how road gradients have a significant impact on energy efficiency has been demonstrated. Driving cycles also show significant impact on an EV energy usage and range. Energy consumption is also influenced by the weight of an EV. The EV's energy usage is impacted by traffic on city streets. Stop-and-go motions consume more energy and squander it. Energy usage is influenced by all of these factors. The State-of-Charge (SOC), temperature, and Coulombic efficiency (CE) of the battery are only a few examples of battery-related variables that affect energy efficiency in an EV. The temperature of the EV is affected by weather conditions changes during the charging and discharging cycles [5]. Since the car can run for longer periods of time with the available power supply, the SoC has an impact on how energy-efficient the vehicle is. The battery loses less power per cycle with a higher CE, which extends the battery's life and boosts the vehicle's efficiency [19]. In other words, as the current drawn increases, the battery's coulombic efficiency will decrease. All the above-mentioned factors play an individual role in the energy consumption of an EV, and therefore consideration of all these factors is necessary when energy estimation is concerned. A comprehensive energy consumption model will facilitate the development of efficient eco-routing systems.

1.2. Significance and motivation

This research aims at offering a solution that can help create a sustainable environment and decrease the rapid increase in pollution at large. Energy conservation is vital in EVs, and therefore this work emphasises the concept of eco-routing, which can maximise energy efficiency in EVs, conserve energy by minimising its use , extend the range of vehicles, and also decrease range anxiety in EVs. The transition to EVs from fossil fuel automobiles is urgently required to reduce the harm caused to the environment. The sharp increase in carbon emissions is concerning, but the idea of eco-routing offers a positive outlook. In the case of EVs, they can be employed as a workable option to reduce energy consumption and achieve optimum efficiency.

According to research, the transportation sector accounts for around 19% of the world's air pollution [20]. As a result, a vehicle navigation tool that reduces energy consumption can be very advantageous for society as a whole. Apart from its potential to stop the growth of emissions, eco-routing has a variety of advantages. According to reports, eco-routing navigation systems could boost energy efficiency and cut conventional internal combustion engine vehicles' (ICEVs) greenhouse gas emissions by 5 to 15% [4]. But for EVs, the benefits of this kind of system go beyond reduced emissions and energy use. The range anxiety of drivers can be reduced with the aid of an eco-routing system, which is crucial for improving the energy economy of the car. Most of the time, it is nearly decided that a driver will select the route with the shortest trip time. However, there has been a significant increase in traffic congestion in practically all major cities throughout the world due to the population of vehicles. According to Ahn and Rakha's 2008 analysis, traffic delays in the US grew significantly between 1982 and 2003. In such situations, it would be prudent on the part of the driver to not rely on prior experience when choosing the route with the shortest travel time [21]. The use of navigation systems by drivers to get real-time traffic updates has increased. Some routes in an eco-routing system, despite being slower, use less energy. Along with lowering personal car fuel consumption, pursuing energy efficiency benefits the entyre transportation industry as well as the environment as a whole. There is a need for an exact model that can accurately approximate the energy usage of the EV in the most applicable manner because numerous aspects are involved in estimating the range and energy consumption of an EV. While energy consumption, EV range, and journey time are the three key factors considered by eco-routing algorithms, they all generally seek to choose the most energy-efficient path. Finding the route with the lowest energy usage and shortest travel time should, however, also be prioritised to prevent any difficulty for the drivers.

The research on eco-routing is still in its early stages because it is a relatively new idea. Reviews of the literature indicate that the majority of modern navigation systems use GPS and concentrate on determining the quickest path. In the case of ICEVs, that is advantageous. On the other hand, the fastest route might not always be the most energy-efficient one, which could be troublesome for EVs [13]. Range is a major problem for EVs, and creating an eco-routing system seems like an unrealistic target. Systems that are now in use have been primarily modelled for ICEVs and are based on speed profiles and traffic data; most research has not yet taken battery economy into account. Additionally, it has been noted that the eco-navigation systems now employed by EVs are proprietary and thus difficult to obtain for testing. A study demonstrates that a successful navigation system depends on a number of variables that are not all taken into account while evaluating it. Another aspect that hinders the creation of effective routing systems is cost. Therefore, creating a user-friendly, comparatively inexpensive eco-routing navigation algorithm by analysing all important aspects, such as road grade and surface conditions, might be able to alleviate range anxiety. According to a literature analysis, if completely adopted, the eco-routing technique may have serious detrimental effects on the network. It should be noted that Eco-routing does not always cut down on travel time, according to a 2012 presentation by Rakha et al. [22]. When taking a less crowded route, the driver might occasionally go much faster, which would increase energy consumption. When choosing the coating for a road surface, it is crucial to take the impact of road surface characteristics, such as macrotexture and unevenness, on rolling resistance and fuel consumption into account. Although there are a wide variety of outcomes in the research, it is still unclear how much of an influence there really is. The motion of a vehicle and, subsequently, its energy consumption are significantly influenced by the rolling resistance. There haven't been any reports yet on how rolling resistance affects different road types and road slopes. On a windy day, cross-wind impacts happen when a car is travelling at a faster pace. That will increase aerodynamic drag, which is a key factor in how much energy an EV uses. Additionally, analysis of cross-wind effects has not yet been incorporated into popular models. There are many restrictions that could have an impact on how much energy an EV uses. Evidently, changes in elevation have an impact on braking, power consumption, and regenerative braking parameters. The amount of time it takes an EV to travel a certain route depends on its length and posted speed limit. Traffic information is another constraint present in these systems. The energy loss can also be affected by auxiliary loads in an EV. High loads shall result in increased power use, despite the fact that an idle EV uses substantially less energy than a typical ICEV idling engine. Less vehicle speed and higher travel times are resultants of increased traffic.

In an EV, a rechargeable battery provides the power for all system operations. It is used to power all other auxiliary components as well as the electric motor that is used for driving the vehicle [23]. The utilisation of the proper battery source must therefore be addressed in EV technology in order to increase the battery's energy capacity for long-distance driving. According to research, using the right battery with a high energy density will allow for farther drives or over more terrain. In the field of energy sources, research has been done on increasing the driving range of EVs. Lithium-ion (Li-ion) and Nickel metal hydride (NiMH)batteries are the two main battery types used in EVs, according to current battery technological developments [24]. However, there is very little research available on the problem of range anxiety experienced by EV users. Driving distance and battery energy capacity are strongly connected. Longer driving distances are produced by batteries with greater energy capacities. The battery life of an EV is frequently determined by its usage. The modelling of batteries can be used to forecast and possibly increase their lifetime. Over the years, numerous different battery models have been created. However, the majority of these published models are only able to compute lives for specific discharge profiles, not for workloads as a whole. When using a battery, a number of things could go wrong. Temperatures in the massive batteries in use may rise, particularly during high-power extraction [19]. Thus, in order to design appropriate controlling algorithms and maintenance techniques that can be employed effectively in electric vehicles and to forecast battery behaviour under varied operating situations, correct battery models are crucial. For an electric vehicle's range to be determined, it is crucial to estimate key battery-dependent factors such as coulombic efficiency, state of charge, and discharge [25]. The above-mentioned factors of road load based on the grade of the road, the type of battery being used, and the appropriate selection of motor for vehicle propulsion must all be taken into consideration when designing an eco-routing system. The key to creating a solid eco-routing navigation system is efficient energy consumption calculation and range determination by taking all essential aspects into account.

1.3. Challenges faced in the EV industry

Transportation plays a significant role in the daily routine of a person. Increased need for travel has opened up opportunities for electric vehicles. There can be no denial that the era of EVs has arrived. EV production and sales have increased significantly in recent years. Many major automakers have made significant investments in EV technology, producing a diverse range of electric vehicles to meet rising demand. EV adoption is accelerating, fueled by rising gasoline prices, greater ranges due to improved battery performance, lower battery costs, and incentives from governments [26]. These are positive trends, but the EV industry faces many pressing challenges.

i. ***Cost of Purchase:*** One of the biggest challenges faced by the EV sector is the high cost of purchase. When compared to conventional vehicles, the initial cost of obtaining an EV is comparatively higher. The high initial cost makes it unaffordable for many prospective purchasers, limiting EV demand. This is primarily due to the high cost of EV battery technology.

ii. ***Range anxiety:*** Range anxiety is the apprehension that battery charge will exhaust while driving. It is a huge impediment for drivers. This difficulty is greater in cold climates, when temperatures below normal can significantly reduce an EV's usual battery range. Although EV ranges have increased, there is still a misconception that EVs may not provide enough range for long-distance driving, particularly in an expanded country like India. The batteries in EVs degrade with time, which might result in a decreased range.

iii. ***Charging infrastructure:*** The paucity of charging outlets is raising range anxiety among drivers. Charging infrastructure, in India, is still in its early phases of development and is centred in major cities [27]. Most charging is seen as being done at home. The lack of a comprehensive and ubiquitous charging network is problematic for EV users, particularly those who live in apartments or do not have dedicated parking places.

iv. ***Battery Technology:*** Batteries are indispensable for EVs. High battery prices are a major reason for the low acceptance of EVs. Currently, lithium-ion technology is most commonly used. Their production requires specific minerals and rare earth elements. Therefore, batteries have to be imported by many countries, including India, leading to increased costs. The lengthy charging time of EVs as compared to the refuelling time of ICEVs negatively affects their convenience and usability.

1.4. Research objectives

1. To develop and analyze a model which shall be based on road load, battery information as well as the power plant information to determine the energy consumption and the range of an electric vehicle during a trip.

    a. To model using road grade data from standard mapping resources and also incorporate vehicle dynamics.

    b. Battery behaviour under various operating conditions in an EV shall also be analysed. Coulombic efficiency and the State of Charge(SoC) of the lead acid battery used in EV shall be calculated which affects the range of the vehicle and thereby tackle issues of range anxiety in EVs.

    c. To develop a test set-up and analyse the torque-speed characteristics of various motors and analysis of efficiency of the motors to be used.

2. To design a test electric vehicle and validate the results of simulation with real time data obtained from the test EV.

    a. Estimation of range of the test EV based on information from the vehicle, road as well the battery and to demonstrate that taking the suggested eco-route minimizes energy consumption as compared to the other routes.

1.5. Thesis Outline

The thesis has been structured into the following chapters for making it accessible to readers.

- Chapter 1: ***Introduction, motivation and challenges***

This chapter provides an introductory understanding of electric vehicle basics, the concept of eco-routing navigation and the influence of energy consumption in electric vehicles. The significance and motivation for this work has been highlighted along with the organisation of the thesis.

- Chapter 2: ***Survey of literature***

This chapter presents a study on the existing literature and state of the art techniques related to eco-routing navigation. The current scenario as well the future of eco-routing has been discussed. The factors affecting energy efficiency in vehicles have been emphasised along with the prevalent energy consumption models.

- Chapter 3*:* ***Design and development of vehicle test bed***

This chapter explains the design and development of a dynamic test bed for this work which comprises of mechanical and chassis development and also the electric drive and circuitry. The motor characteristics, the various sensors as well as the data acquisition system used have been clearly explained. The final product with few results has been presented at the end.

- Chapter 4: ***Road load model analysis***

This chapter presents a detailed analysis on road load and tractive effort in electric vehicles. Forward vehicle dynamics have been discussed in details along with a road surface estimation. A road load model has been simulated with special emphasis on road grade. The model design and simulation results have been presented at the end of the chapter.

- Chapter 5: ***Batteries for EV and their parameter extraction***

This chapter outlines the basics of lead acid batteries in EV technology and explains the concept of Coulombic efficiency (CE). A simple electrical circuit battery model has been presented focusing on the effects of battery in eco-routing navigation of electric vehicles. A system to measure the CE was developed which has been highlighted along with working principle, necessary calculations and circuitry information. The results have been discussed in details.

- Chapter 6: ***Energy consumption estimation for eco-routing***

In this chapter, an energy consumption estimation technique has been presented. The factors influencing energy efficiency have been identified and studied in detail. The dynamic test bed has been used to obtain real time results which have then been processed to obtain the energy consumption during a specific trip. The energy consumption has been used in estimation of range of the test EV as well as in determination of an eco-route. The influence of aerodynamic drag, driving cycle, road grade, rolling resistance and tyre pressure in the energy usage of the EV have been analysed elaborately. In addition, prediction of energy consumption using a neural network model has also been shown. All results have been discussed in details at the end of the chapter.

- Chapter 7: ***Conclusion and future scope***

This chapter provides the conclusions and the future scope of work.It summarises the overall work done highlighting the main contributions of the thesis.The applications of this research work has also been mentioned.

References

[1] *Benefits of electric car on the environment*. Retrieved on 07 Jan. 2023 from https://www.edfenergy.com/energywise/electric-cars-and-environment, 2023

[2] Singh, A. *India's EV Economy: The Future of Automotive Transportation*. Retrieved on 07 Mar. 2023 from https://www.investindia.gov.in/team-india-blogs/indias-ev-economy-futureautomotivetransportation#:~:text=The%20Econo mic %20Survey%202023%20predicts,and %20indirect%20jobs%20by%202030.

[3] Minett, C.F., Salomons, A.M., Daamen, W., Van Arem, B. and Kuijpers, S. Eco-routing: comparing the fuel consumption of different routes between an origin and destination using field test speed profiles and synthetic speed profiles. In *IEEE Integrated and Sustainable Transportation System (FISTS),* pages 32-39, IEEE Forum, 2011.

[4] Nealon, S. *Cutting Electric Vehicle Energy Use 51 Percent*. Retrieved on 07 Mar. 2016 from http://ucrtoday.ucr.edu/24361,September 2014.

[5] Sweeting, W.J., Hutchinson, A.R. and Savage, S.D. Factors affecting electric vehicle energy consumption. *International Journal of Sustainable Engineering*,4(3):192 -201, 2011.

[6] *Advantages and Disadvantages of Electric Vehicles.* Retrieved on 12 Jul. 2019 from https://intellipaat.com/blog/advantages-and-disadvantages-of-electric-vehicles/, 2018.

[7] Wang, J., Besselink, I. and Nijmeijer, H. Electric vehicle energy consumption modelling and prediction based on road information. In *Proceedings of the EVS28 International Electric Vehicle Symposium and Exhibition*, pages 3-6, Kintex, Korea, May 2015.

[8] *Electric vehicle*. Retrieved on 10 May, 2017 from https://en.wikipedia.org/wiki/Electric_vehicle, 2005.

[9] *History of the electric vehicle*. Retrieved on 10 May 2017 from https://en.wikipedia.org/ wiki/History _of _ the _electric_vehicle, 2014.

[10] *Electric Vehicle Basics*. Retrieved on01 Jul. 2019 from https://www.energy .gov/eere/ electricvehicles/electric-vehicle-basics, 2019.

[11] *FAME India Scheme.* Retrieved on 16 Mar. 2020 from https://pib.gov.in/PressReleasePage.aspx ?PRID=1577880, 2019.

[12] *Electric vehicle industry in India*. Retrieved on 20 Aug. 2017 from :https://en.Wikipedia. org/wiki/Electric_vehicle_industry_in_India, 2015.

[13] Philip, L. *How government plans to make India an electric vehicle nation* .Retrieved on 12 Jan. 2019 from http://economictimes.indiatimes.com /industry/auto/news/industry/how-government-plans-to-make-india-an-electric-vehicles nation/articleshow/60398935.cms , September 2017.

[14] All electric vehicles. Retrieved on 19 Apr. 2021 from https://www.fueleconomy .gov/feg/evtech.shtml.

[15] Wu, G., Boriboonsomsin, K. and Barth, M.J. Eco-routing navigation system for electric vehicles. *arXiv preprint arXiv:2008.09674*, 2020.

[16] Zhang, Y., Wang, W., Kobayashi, Y. and Shirai, K. Remaining driving range estimation of electric vehicle. In *IEEE Electric Vehicle Conference (IEVC),* pages1-7, March 2012.

[17] The Benefits of Driving Electric Cars. Retrieved on 04 Nov. 2022 from https://pod-point.com/guides/driver/benefits-of-electric-cars#:~:text=Electric%20cars%20are%20far%20more,you%20from%20A%20to%20B.

[18] *How to make the most of your tyres on an electric vehicle*.Retrieved on 10 Nov. 2021 from https://www.electronicspecifier.com/products/renewables/how-to-make-the-most-of-your-tyres-on-an-electric vehicle #:~:text =Excessively%

20low%20tyre%20pressure%20and,above%20the%20car%20manufacturer's%20recommendation,September 2020.

[19] Sharma, S., Sarma, P., Bordoloi, S. and Barman,P. Estimation of coulombic efficiency of lead acid battery for range determination of electric vehicle, in: *IEEE 2015 1st Conference on Power, Dielectric and Energy Management at NERIST (ICPDEN)*, pages 1–6, January,2015.

[20] Magrath, J. and Brady, M. Evaluating different methods for determining road grade best suited to advanced bus transportation systems. *In IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*, pages 108–113, September 2017.

[21] Ahn, K. and Rakha, H. The effects of route choice decisions on vehicle energy consumption and emissions. *Transportation Research Part D: Transport and Environment*, *13*(3):151-167, 2008.

[22] Rakha, H.A., Ahn, K. and Moran, K. Integration framework for modeling eco-routing strategies: Logic and preliminary results. *International Journal of Transportation Science and Technology*, *1*(3):259-274, 2012.

[23] Ji, X., Zhang, X. and Liu, Y. Modeling and simulation of brushless dc motor control system for EPS applications. In *IEEE International Conference on Computer Science and Automation Engineering (CSAE),* Vol. 3, pages 279-284, China, May 2012.

[24] Hanifah, R.A., Toha, S.F. and Ahmad, S. Electric vehicle battery modelling and performance comparison in relation to range anxiety. *Procedia Computer Science*, *76*:250-256, 2015.

[25] Zhang, C., Li, K., Mcloone, S. and Yang, Z.Battery modelling methods for electric vehicles-A review. In *IEEE European Control Conference (ECC),* pages 2673-2678, France, June 2014.

[26] *10 Biggest Challenges Facing the EV Industry Today.* Retrieved on 07. Jul 2023 from https://evchargingsummit.com/blog/challenges-facing-the-ev-industry-today/.

[27] *Electric Vehicles: The Advantages and Challenges.* Retrieved on 07. Jul. 2023 from https://www.drishtiias.com/daily-updates/daily-news-editorials/electric-vehicles-the-advantages-and-challenges,May 2023.