THE POTENTIAL OF KENYA'S SUSTAINABLE ENERGY TO EXCLUSIVELY MEET ELECTRIC VEHICLES ELECTRICITY DEMAND

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

This thesis is dedicated to my beloved family, whose unwavering support, prayers, and encouragement sustained me throughout this academic journey.

To my parents, for instilling in me the values of resilience and the pursuit of knowledge.

To my mentors and friends who continually inspired me to press on despite challenges.

And to all future scholars in the field of sustainable energy and electric mobility may this work contribute, even in a small way, to the advancement of clean and equitable energy solutions for our continent.

ABSTRACT

This study investigates the potential of sustainable energy resources to exclusively satisfy the electrical energy demand of electric vehicles (EVs) in Kenya by examining vehicle growth dynamics, charging infrastructure development, and projected electricity requirements up to 2063 in tandem with Africa’s AGENDA 2063 initiative. Analysis of fleet data shows that internal combustion engine vehicles (ICEVs) remain dominant, expanding from approximately 1.4 million units in 2010 to 4.88 million in 2024, while EVs adoption, which began in 2016, reached 9,019 units by 2024, with motorcycles accounting for nearly 90% of registrations. Although EVs currently represent only 0.02% of the national fleet, their accelerated growth since 2021 is supported by rising fuel prices, supportive policies, heightened environmental awareness, and gradual improvements in charging infrastructure. Projections from the regression analysis of historical data up to 2024 suggest that the number of EVs could reach 8.2 million by 2063. On the other hand, projection using Logistic Growth Model (LGM), which theoretically describes diffusion of an innovation in the society, predicts that the number of EVs by 2063 could reach 5087062, 9246810, 10795415 and 11122187 respectively for conservative (25%), moderate (50%), optimistic (75%) and original (100%) growth scenarios. Thus, the EVs adaption in the country can best be described by the moderate scenario because it closely matches that from regression analysis of historical data with a deviation of 12.8%. The evaluation of charging infrastructure reveals that facilities remain highly uneven and urban-centric, with Nairobi dominating while peripheral regions lag behind; BasiGo, Holy Family Basilica, and Charge Net lead the sector, and Level 2 charging is most common, with limited Level 3 and no Level 1 installations, suggesting a strategic prioritization of mid-tier charging technologies but highlighting the need for regionally inclusive infrastructure. Projected electricity demand from EVs varies between 24.33 TWh and 53.19 TWh by 2063, and when combined with domestic and industrial growth, national requirements could reach between 54.25 TWh and 83.11 TWh, equivalent to 6193 – 9488 MW. Kenya’s renewable energy capacity is projected to grow from 2323 MW in 2024 to 6887 MW by 2063, hence will be insufficient to meet the highest projected demand with a deficit of 2601 MW. Fortunately, the country possesses vast untapped sustainable energy reserves that are technically viable such as micro-hydro, geothermal, wind and solar energy. Therefore, with timely investment, policy intervention, and nationally balanced infrastructure planning, Kenya has the potential to meet future EVs’ electricity demand entirely through sustainable energy resources, thereby supporting a transition towards a clean and low-carbon transport system.

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LIST OF ABBREVIATIONS

EVs	Electric Vehicles
ICEVs	Internal Combustion Engine Vehicles
KNBS	Kenya National Bureau of Statistics
NTSA	National Transport and Safety Authority
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
MATLAB	Matrix Laboratory (numerical computing software)
SDGs	Sustainable Development Goals
IEA	International Energy Agency
LGM	Logistic Growth Model
BAU	Business-As-Usual
CO_2	Carbon Dioxide
GHG	Greenhouse Gases
H_2O	Water (vapor)
SF_6	Sulphur Hexafluoride
CO	Carbon Monoxide
N_2O	Nitrous Oxide
UN	United Nations
NOx	Nitrogen Oxides
SO_2	Sulphur Dioxide
PM	Particulate Matter
U.S. EPA	United States Environmental Protection Agency
BEVs	Battery Electric Vehicles

EU	European Union
UNFCCC	United Nations Framework Convention on Climate Change
KOSAP	Kenya Off-Grid Solar Access Project
EMAK	Electric Mobility Association of Kenya
VAT	Value Added Tax
AMG	AMG Advocates
CIF	Climate Investment Funds
IPCC	Intergovernmental Panel on Climate Change

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The climate crises wrecking the world today have become one of the greatest concerns of the 21st century, with extreme weather events (extended droughts and severe floods), biodiversity loss, and rising global temperatures posing significant threats to ecosystems and human health (World Economic Forum, 2024; Ripple et al., 2024). Human activities across all economic sectors, and indeed all natural processes, require energy to operate, and the major source of the energy utilized is the fossil fuels in any of the three physical states, i.e. coal, oil, and natural gas. Utilization of fossil fuels involve combustion process which converts chemical energy stored in these fuels into mechanical energy which in turn do useful work and in the process release carbon dioxide (CO_2) and other greenhouse gases (GHGs) that trap heat in the atmosphere, significantly contributing to global warming (WWF, 2023; Met Office, 2023). According to Ruiz (2024), the energy sector, heavily reliant on fossil fuel, remains the largest contributor to GHG emissions, responsible for over 75% of global emissions, as shown in Figure 1.1(a).

The energy sector encompasses a wide range of activities related to the production, conversion, distribution, and consumption of energy, (IEA, 2023). These include electricity and heat generation, transportation, manufacturing and construction, fugitive emissions from fuel production and distribution, building operations, and other fuel combustion (Ruiz, 2024). As shown in Figure 1.1(b), electricity generation and transportation are the leading contributors, accounting for 42.1% and 22.4% of emissions, respectively.

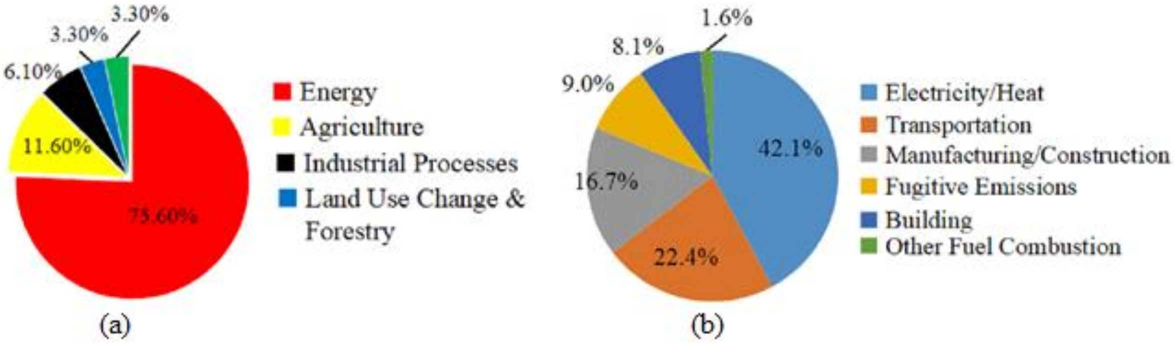

Figure 1.1: Global GHG emissions from, (a) different economic sectors, and (b) different utilization of energy (Ruiz, 2024)

Internal combustion engine vehicles (ICEVs), which include cars, trucks and motor cycles, are powered by petroleum or hydrocarbon fuels. These fuels are burnt by the engines to convert thermal energy into mechanical energy for vehicle propulsion. In addition, a complete combustion of the fuel produces carbon dioxide (CO_2) and water vapor (H_2O) as byproducts or exhaust gases (Martins, and Brito, 2020). For instance, the complete combustion of the simplest hydrocarbon, i.e. methane, is given by:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O(g) + energy \tag{1.1}$$

The energy released in equation (1.1) is used to drive the vehicle, while the exhaust gases are emitted into the atmosphere as pollutants. The mass units of CO_2 gas and H_2O vapor in equation (1) are 44 and 36 units respectively in the 80 mass units of products. Therefore, complete combustion of one mole of methane generates more CO_2 at 55% than water vapor at 45%, which explains the heavy GHG emissions in the transportation sector. Hydrocarbon fuels consumed in road transport have different carbon-number varying from 5-10 for gasoline, and 14-20 for diesel while for aviation and marine transport have respectively carbon-number of 10-16 for jet fuel and 20-70 for heavy fuels (Altin, and Eser., 2004). As the carbon-number in these fuels increases, the CO_2 emitted increases proportionally and hence emission levels. For incomplete combustion of petroleum fuels, other byproducts are emitted such as Sulphur hexafluoride (SF_6), carbon monoxide (CO), hydrocarbons and nitrogen oxides (N_2O) and soot or particulate matter (Ghosh, 2020). These gases cause air pollution, which has been associated with various health issues to people. The road transport accounts for over 70% of the total GHG emission from transportation industry as compared to the rest of the transportation methods (Higueras-Castillo, 2021; Calderon-Tellez et al., 2023). The air pollution from GHG emissions by road transport is a big challenge in big cities in the world due to the large population and high traffic concentration (Ajayi et al., 2023). This menace has made these cities unsustainable prompting the inclusion of SGD#11 on building sustainable cities (UN, 2015). There is, therefore, a need to reduce GHG emission in the transportation sector, and proposed methods include technology advancements, policy interventions, fuel switching, and shifts in consumer behavior (Ayetor *et. al*. 2021,).

Transition to renewable energy has emerged as a crucial method for decarbonizing the power sector and enhancing energy system resilience. Attanayake et al. (2024) asserts that technologies like solar, wind, and hydropower possess significant potential for mitigating GHG emissions when systematically included into national grids. Kabeyi and Olanrewaju (2021) agrees that the shift from fossil fuels to renewable energy reduces the carbon intensity of power generation and supports global initiatives for energy independence and sustainability. IRENA (2021) emphasizes that augmenting renewable energy capacity especially through diversified energy mix can improve the stability and reliability of power systems, particularly amid rising demand and climate-related disturbances. In addition to environmental and operational advantages, Gayen et al.

(2023) remarked that renewable energy production contributes significantly to socio-economic benefits, including employment creation and local industrial growth.

In response to the urgent need to reduce GHG emissions, the electrification of the transport sector has gained prominence as a critical pathway toward decarbonization, particularly when powered by renewable energy sources (Speizer et al., 2024). Electric vehicles (EVs) have emerged as a cornerstone of this transition, offering significant environmental advantages over internal combustion engine vehicles (ICEVs) due to their superior energy efficiency and elimination of tailpipe emissions (IEA, 2023). Unlike ICEVs, which release substantial amounts of nitrogen oxides (NO_x), sulphur dioxide (SO_2), and particulate matter (PM), EVs produce no local emissions, thereby improving urban air quality and public health outcomes (Woo et al., 2022). Lifecycle assessments reveal that battery electric vehicles (BEVs) reduce GHG emissions by 60–69% compared to gasoline-powered vehicles even when upstream electricity emissions are considered, with reductions exceeding 80% in regions reliant on renewable energy (Zheng et al., 2021; Best et al., 2022). The sustainability of the electricity mix is thus central to maximizing EVs' climate benefits, as emphasized by Gómez and Jochem (2020). This global shift is reinforced by ambitious policy frameworks such as the European Commission’s mandate for all new vehicles sold in the EU to be zero-emission by 2035, reflecting an institutional commitment to accelerating the transition to low-carbon mobility systems (Jones, 2023).

Kenya is on an ambitious mission to achieve 100% of clean energy generation by 2030. Currently, approximately 90% of Kenya's electricity is derived from renewable sources primarily geothermal, hydropower, and an increasing contribution from solar and wind energy (KNBS, 2024). This strategic focus not only supports efforts to reduce GHG emissions but also positions the country to align with global climate goals such as those outlined in the Paris Agreement (UNFCCC, 2016). Recognizing the need for a resilient energy grid, the government has implemented various initiatives to enhance grid flexibility, including the Kenya Off-Grid Solar Access Project (KOSAP), which aims to expand access to clean electricity in underserved regions (Energy and Petroleum Ministry, 2024).

The EVs in Kenya have experienced notable growth, with registered EVs increasing from 2,694 in 2023 to 5,294 in 2024 (Electric Mobility Association of Kenya, EMAK, 2024). Despite this progress, ICEVs continue to dominate due to their affordability and entrenched market presence. While ICEVs remain prevalent due to affordability and established market presence, EV adoption is increasing, supported by growing consumer interest and government incentives. These incentives include reduced import duties, excise duty exemptions, and removal of VAT on EVs, which have made them more accessible to Kenyan consumers (Automag, 2025). Additionally, the government introduced green-colored number plates for EVs to promote visibility and public awareness, encouraging a shift towards cleaner transportation options (Ministry of Transport, 2024). Nevertheless, the sector faces significant challenges, such as high initial purchase costs, inadequate charging infrastructure, and limited operator knowledge (Mani and Maina, 2024).

To further accelerate EV uptake, Kenya launched a comprehensive National Electric Mobility Policy in 2024, outlining strategies for local manufacturing and assembly of EVs, expansion of charging infrastructure, and development of technical capacity in the e-mobility sector (AMG Advocates, 2024). The policy also emphasizes inclusivity, aiming to empower women, youth, and persons with disabilities to participate in the emerging EV industry (Vellum, 2024). These initiatives position Kenya as a regional leader in electric mobility, with goals to reduce greenhouse gas emissions, decrease reliance on fossil fuels, and stimulate economic growth and job creation in the clean technology sector (IEA, 2022).

The widespread adoption of EVs is projected to significantly increase electricity demand, raising concerns about the readiness and stability of existing power infrastructure. A study by the Kapustin and Grushevenko (2020) estimated that by 2040, electric vehicles could account for 11–28% of the global road transport fleet, resulting in an 11–20% increase in global electricity consumption. In 2023, EVs consumed approximately 130 TWh globally representing about 0.5% of global final electricity use, with higher shares in China and the European Union (IEA, 2024). Regional variations are evident: in China, electric two/three-wheelers and buses made up nearly 30% of EV electricity use, while in the U.S., passenger cars accounted for over 95% of total EV electricity demand. In anticipation of similar trends, Indonesia anticipates an additional 29,300 MW of load by 2030 due to EV uptake (Tampubolon and Dalimi, 2023).

Accurately assessing the impact of EV charging on electricity distribution networks is vital to avoiding grid instability, as highlighted by Vyas et al. (2023). The effective integration of EVs with renewable energy sources is equally essential for enhancing energy efficiency and achieving broader climate objectives (Al-Ghaili et al., 2022). Moreover, Ajao et.al (2024) emphasize the need to embed both behavioral and infrastructural factors into policy frameworks to ensure successful adoption and long-term grid reliability. These challenges are particularly relevant to Kenya, where the EV sector is rapidly expanding alongside a renewable energy-driven power system. In response, this study investigates the extent to which Kenya's renewable energy resources can meet the electricity demands of EVs, analyzing both present capacity and future projections. By employing modeling techniques, comparative analysis, and a review of relevant policies, the research aims to generate useful insights that support the sustainable development of Kenya's transport and energy sectors.

1.2 Statement of the Problem

Kenya's transportation sector is heavily reliant on fossil fuels, exposing the country to global fuel price fluctuations and high domestic taxation, which have contributed to increased transportation costs. In addition, over-reliance on these fuels escalates environmental degradation through GHG emissions and air pollution. In response, EVs are increasingly being promoted as a cleaner and more sustainable transportation alternative. Kenya is well-positioned to support EVs integration, with about 90% of its electricity currently sourced from renewable energy sources such as geothermal, hydropower, wind, and solar (KNBS, 2024). The government's target to achieve 100% clean energy by the year 2030 and the ongoing investments in grid flexibility and off-grid access (Energy and Petroleum Ministry, 2024; CIF, 2024) further reinforce this initiative. However, the key challenge lies in determining whether the country's renewable energy capacity can sustainably meet the future electricity demand of a rapidly expanding EV fleet. This study addresses the knowledge gap on the technical and energy feasibility of exclusively powering EVs using renewable resources in Kenya. It seeks to examine the trends in EV growth, vehicle energy consumption characteristics, and projected electricity needs by 2063 (in tandem with Africa's AGENDA 2063 initiative), in relation to the country's existing and planned renewable energy capacity.

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study was to explore the level of penetration of EVs vis-a-vis ICEVs in the transportation industry in Kenya and present insight into the future mobility based entirely on the pure EVs and the potential of the country to exclusively power them from the sustainable energy resources.

1.3.2 Specific objectives

The specific objectives of this research were:

i. To determine the growth rate of EVs in relation to ICEVs and types of electric automobiles from 2010 to the 2024 registered in Kenya, and hence project the number of EVs in Kenya by the year 2063.

ii. To determine the available charging processes and driving range (autonomy) for full battery charge of the existing types of EVs in Kenya.

iii. To determine the capacity of the country's sustainable energy resources to exclusively meet the energy demand in the 2063.

1.4: Justification for the study

Global efforts to mitigate climate change emphasize the decarbonization of all economic sectors, especially the hard-to-green industries such as transportation, cement, and steel production (IPCC, 2023). The transportation sector remains one of the largest contributors to GHG emissions due to its heavy reliance on ICEVs, making the transition to EVs complex and urgent (IEA, 2024). In Kenya, the diversity and number of fossil-fuel-powered vehicles, coupled with constraints in electricity supply infrastructure, present significant hurdles for EV adoption (Kenya Ministry of Energy, 2023; KNBS, 2024). These challenges raise critical questions about the capacity of Kenya's electricity grid to support a growing EV fleet sustainably.

This study seeks to evaluate the feasibility of integrating EVs into Kenya's transportation sector by examining electrification rates, existing EV technologies, battery performance, charging infrastructure, and the renewable energy capacity needed to power EVs exclusively. The findings will contribute to achieving Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) (United Nations, 2015). Furthermore, this research supports Kenya's commitments under the Paris Agreement (UNFCCC, 2016) and Africa's Agenda 2063 by informing policies that promote clean energy transition, economic growth, and environmental sustainability (African Union Commission, 2015).

CHAPTER TWO

THEORY AND LITERATURE REVIEW

2.1 Introduction

This chapter explores the theoretical foundations and existing literature relevant to assessing the potential of sustainable energy resources to exclusively satisfy the electrical energy demand of electric vehicles (EVs) in Kenya. It begins by examining key theories, including those related to sustainable energy, electric vehicle adoption, and energy demand estimation, which provide the necessary framework for understanding the interplay between EVs and sustainable energy systems. Next, a review of literature related to the specific objectives will be presented to establish the contest of research and identify the gaps.

2.2 Theoretical Framework

The successful integration of EVs into Kenya's transportation sector, powered predominantly by sustainable energy sources, is a complex process influenced by various socio-technical dynamics. To analyze this transition, a robust theoretical framework is essential. This research will primarily draw upon the Diffusion of Innovations (DOI) theory and the broader concept of energy transition. The DOI theory provides insight into how EV technology and associated infrastructure are adopted by different user groups, highlighting the role of innovation attributes, social systems, and communication channels. Meanwhile, the energy transition perspective allows for an examination of the structural shift from fossil fuel dependency to a renewable-based energy system, encompassing technological, policy, economic, and behavioral changes. Together, these approaches offer a comprehensive lens to assess Kenya’s capacity to meet future EV electricity demands sustainably, while identifying key drivers, challenges, and opportunities within this evolving energy landscape.

2.2.1 Diffusion of Innovation Theory

The diffusion of innovation theory, originally developed by Everett Rogers, describes how new ideas, products, or practices spread within a social system over time through specific communication channels (Hornor, 2022; Guo and Huang, 2024). The theory identifies four key elements: the innovation itself, communication channels, time, and the social system, and outlines the adoption process as progressing through stages of knowledge, persuasion, decision, implementation, and confirmation, often visualized as an S-shaped adoption curve (Hornor, 2022; Guo and Huang, 2024) . Rogers' model has been foundational across disciplines, influencing research in health care, marketing, and technology, and has inspired further models such as Moore's "crossing the chasm" and the Bass model, which use mathematical and managerial perspectives to predict and manage the spread of innovations (Guidolin and Manfredi, 2022).

Figure 2.1 shows how a typical innovation Rogers's bell curves (Henderson, 2017). This model indicates that innovators are the first group of people to take up a new technology or try a new product and are usually small in number. They are then followed by 'early adopters' with slightly higher number, then the 'early and late majority' on either side of the peak of the curve, and finally the 'laggards' succumb and begin using the new invention of product.

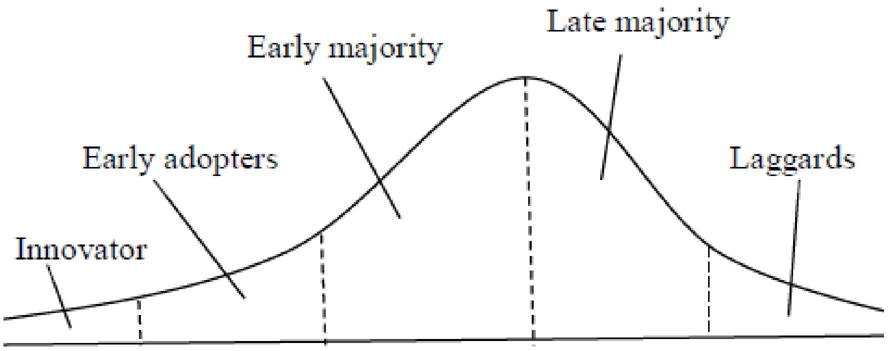

Figure 2. 1: Typical Rogers innovation bell curve (Henderson, 2017)

Innovators constitute a small, risk-tolerant segment that actively seeks novel ideas (Dedehayir et al., 2017). Early adopters, often-respected opinion leaders, follow closely behind and significantly shape the perceptions of the broader public (Chen, 2024). The early majority adopts innovations just before the average individual, relying heavily on peer validation and demonstrated utility (Martínez et al., 1998). Conversely, the late majority exhibits greater skepticism, adopting primarily due to peer pressure or economic necessity. Laggards, the most resistant group, are often influenced by tradition and adopt only when necessary (Goldenberg, 2007).

Recent studies emphasize that diffusion is not a simple, unidirectional process, but involve dynamic interactions among all actors in an ecosystem, with institutional and contextual factors playing a significant role (Vargo et al., 2020; Dearing and Cox, 2018; Takahashi et al., 2024). Factors such as population size, heterogeneity in consumer learning and innovativeness, and the fit between innovation and user needs also affect adoption rates (Guo et al., 2024). Empirical studies show that diffusion often occurs in successive waves, with interest, patenting, and academic attention peaking at different times (Takahashi et al., 2024). The theory has evolved to inform intervention design, highlighting the importance of opinion leaders, contextual adaptation, and strategies to accelerate the uptake of beneficial innovations while addressing barriers to diffusion (Dearing, 2009; Dearing and Cox, 2018; Guidolin and Manfredi, 2022).

In the context of Kenya's evolving transport and energy systems, DOI theory provides a lens for understanding how EV technologies penetrate the market, the characteristics of early adopters, and the systemic barriers to widespread EV adoption, such as cost, infrastructure limitations, and limited consumer awareness. As electric mobility becomes more visible and its benefits more evident particularly cost savings, environmental impact, and policy support DOI helps explain the dynamics influencing its uptake. Importantly, DOI also highlights the role of institutional actors, policy, communication channels, and social influence, all of which are critical in Kenya's transition toward e-mobility and sustainable electricity demand planning. By applying DOI theory, this study evaluates the pace and scale at which EV adoption could grow in Kenya, thereby projecting the potential demand that EVs may place on the electricity grid and assessing whether existing or potential sustainable energy resources can accommodate that shift.

2.2.2 Energy Transition

Energy transition theory explores the complex shift from fossil fuel-based energy systems to more sustainable, low-carbon alternatives, emphasizing that this process is not only technological but also deeply social, economic, and political (Yang et al., 2024; Cherp et al., 2018; Hirt et al., 2020). The theory highlights both explicit transitions such as changes in energy sources, infrastructure, and consumption patterns and implicit transitions, including shifts in energy governance, justice, and geopolitical dynamics (Yang et al., 2024).

Scholars increasingly use socio-technical transition frameworks, which view energy transitions as the co-evolution of technology, markets, policy, and society, and stress the importance of governance, stakeholder engagement, and institutional arrangements (Cherp et al., 2018; Nora et al., 2022). Research shows that energy transitions are highly context-dependent, shaped by regional, economic, and political factors, and requires coordinated action across multiple scales and actors (Lu and Nemet, 2020, Wood et al., 2019). The literature also underscores the need for just transitions that address social equity and avoid negative impacts on vulnerable populations (Yang et al., 2024). Recent studies call for integrating quantitative models with socio-technical theories to better capture the interplay between technology, society, and policy, and to provide more practical solutions for climate and energy challenges (Hirt et al., 2020).

In Kenyan, Energy Transition Theory is instrumental in examining how renewable energy resources such as geothermal, wind, solar, and hydro are progressively integrated into the national grid and how this shift supports or constrains the adoption of new electricity demands, such as those from EVs. The theory enables an assessment of whether Kenya's electricity supply system, guided by Vision 2030, SDG 7, and the National Energy Policy, is resilient and flexible enough to accommodate emerging sectors without compromising sustainability. By applying this theory, the study evaluates Kenya's energy landscape readiness to support full-scale EV electrification**,** focusing on how policy, infrastructure, and technological development intersect to enable or hinder such a transition.

2.3 Electric Vehicles and Charging Infrastructure

The EVs represent a transformative shift in the transportation sector, offering a cleaner and more energy-efficient alternative to traditional ICEVs. As EV adoption accelerates globally, the development and deployment of reliable charging infrastructure have become central to supporting their widespread use. .

2.3.1 Electric Vehicles

EVs are usually classified based on their energy source and propulsion technology as shown in Figure 2.2.

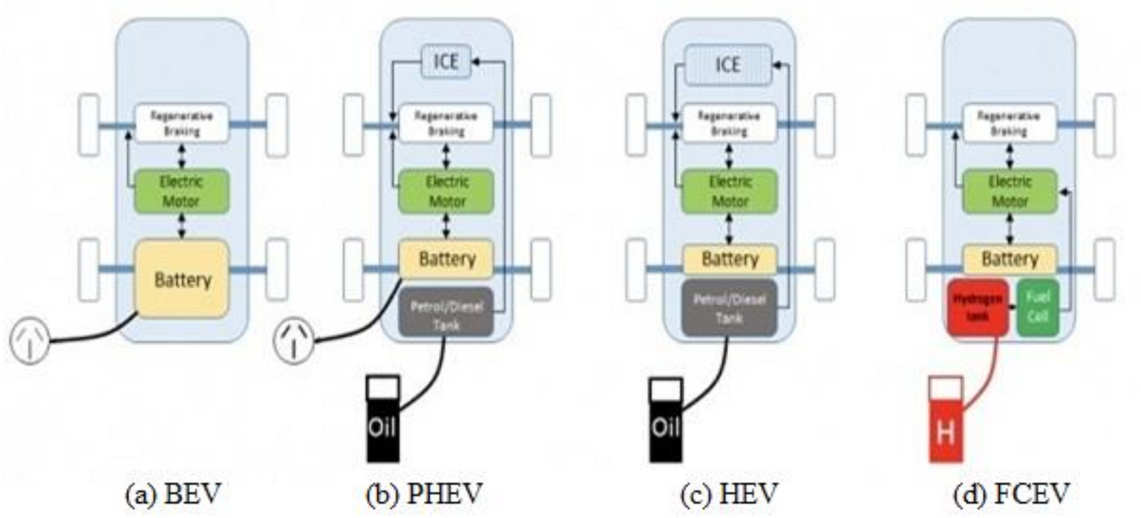

Figure 2.2: Types of electric cars, (a) BEV, (b) PHEV, (c) HEV, and (d) FCEV (Omazaki, 2025)

The common types of EVs are Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs). BEVs operate solely on electricity stored in batteries and are central to decarbonization efforts due to their zero tailpipe emissions (Sanguesa et al., 2021; Haghani et al., 2023). HEVs combine an internal combustion engine with an electric motor, utilizing regenerative braking and the internal combustion engine to charge the battery, and are widely regarded as a transitional technology toward full electrification (Ehsani et al., 2021). PHEVs are similar to HEVs, but with larger batteries that can be charged by plugging into an external power source (Sanguesa et al., 2021).

FCEVs, which generate electricity onboard using hydrogen fuel cells and emit only water vapor, offer long ranges and rapid refueling, though they require a dedicated hydrogen infrastructure (Selmi et al., 2022). In developing economies such as Kenya, the deployment of BEVs and PHEVs aligns more realistically with existing grid capacity, while FCEVs and dynamic charging systems remain long-term prospects due to infrastructure and investment constraints. This study specifically focuses on electric vehicles that operate exclusively on electricity and do not rely on fossil fuels. Therefore, BEVs are central to this research, while HEVs and PHEVs, which still depend partially on gasoline, are excluded from the analysis. FCEVs are also considered outside the immediate scope due to infrastructural limitations in Kenya.

2.3.2 EV charging infrastructure and methods of charging

The EV charging infrastructure is commonly classified based on charging speed, deployment location, and underlying technological architecture. The primary categories encompass residential and workplace charging typically utilizing Level 1 or Level 2 alternating current (AC) as well as public and high-capacity fast-charging stations, which employ direct current (DC) to facilitate rapid energy transfer (Saraswathi and Ramachandran, 2024). While residential and workplace chargers offer convenience and cost-effectiveness for routine commuting, they are constrained by longer charging durations. In contrast, DC fast chargers, predominantly located in public or commercial spaces, significantly reduce charging time and are thus integral to long-distance travel and commercial fleet operations.

Level 1 charging utilizes standard residential outlets, typically 120 V AC in North America, and provides a relatively low power output of approximately 1 to 2 kW. This mode is predominantly suited for overnight residential charging due to its extended charging duration (Yilmaz and Krein, 2012). Level 2 charging, as delineated by Bao et al. (2021) and Sayed and Massoud (2022), operates at voltages ranging from 220 to 240 V AC, with power delivery between 3 and 19 kW. It is widely adopted in residential, workplace, and public settings, offering faster charging times while remaining compatible with existing AC infrastructure. In contrast, Level 3 charging commonly referred to as DC fast charging operates at significantly higher voltages, typically between 400 and 900 V DC, and delivers power levels ranging from 50 kW to over 350 kW (Habib et al., 2017; Dusmez et al., 2011). This technology enables rapid energy transfer suitable for commercial and high-traffic environments but necessitates robust electrical infrastructure, including three-phase AC input and specialized equipment for AC-to-DC conversion (Sayed and Massoud, 2020). Level 1 and Level 2 chargers use single-phase AC power, while Level 3 chargers use three-phase AC supply, which are rectified into direct current for battery charging.

The EV charging methods are broadly categorized into battery exchange, conductive charging, and wireless charging as illustrated in **Figure 2.3**.

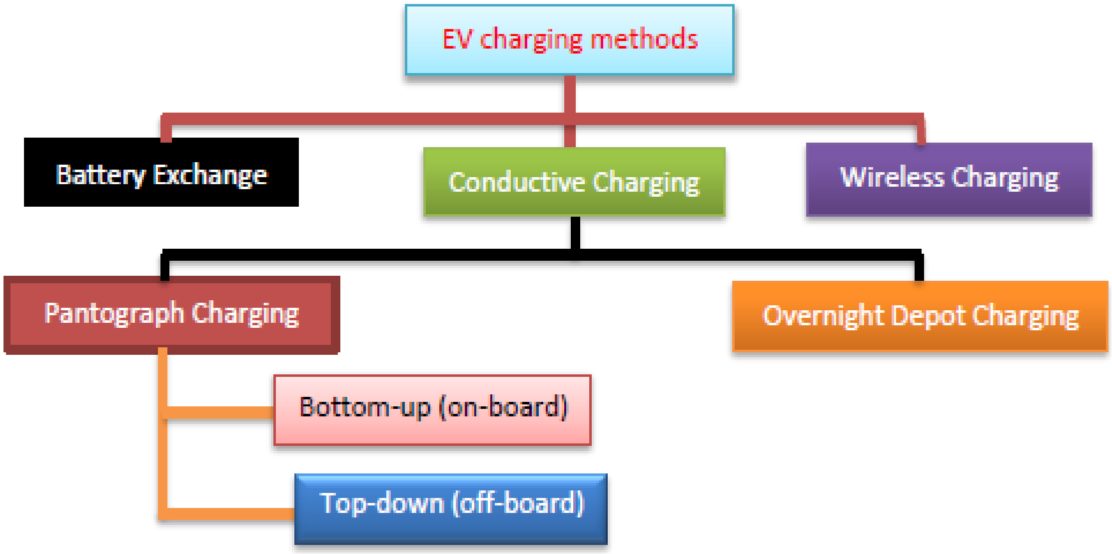

Figure 2.3: EV charging methods. (Arif et al., 2021)

The conductive charging is the most dominant approach due to its operational simplicity, cost-effectiveness, and compatibility with existing electrical infrastructure (Vikram et al., 2024; Hemavathi and Shinisha, 2022). This method encompasses both overnight depot charging, commonly employed in fleet applications during off-peak hours, and pantograph charging, which is particularly suited for electric buses and heavy-duty vehicles. Pantograph systems are further classified into bottom-up (on-board) configurations, where the charger is embedded within the vehicle, and top-down (off-board) systems, where the charger is located externally and power is transmitted from infrastructure to the vehicle (Safayatullah et al., 2022). In contrast, battery exchange, also known as battery swapping, allows for quick replenishment of energy by replacing a depleted battery with a fully charged unit. While this technique offers minimal downtime, its scalability is limited by the lack of battery standardization and high initial infrastructure investment.

Wireless charging includes both static and dynamic (in-motion) technologies and is valued for its potential to automate charging processes, though challenges remain with respect to system efficiency, alignment, and cost (Nezamuddin et al., 2021; Vikram et al., 2024). Recent technological advancements have introduced smart charging strategies that enable demand-side management and real-time grid interaction. These include the integration of renewable energy sources and hybrid systems combining grid-connected and off-grid operations to enhance resilience and sustainability (Kumar et al., 2024; Rivera et al., 2023). The design and accessibility of charging infrastructure have profound implications for grid stability, user convenience, and the equitable expansion of electromobility, particularly in regions with infrastructural disparities (Sachan et al., 2020). Consequently, a diversified and strategically planned charging network is imperative to support the widespread adoption of EVs.

2.4 Global Perspectives on Sustainable Energy and Electric Vehicles

The global push toward EVs is increasingly intertwined with the broader transition to sustainable energy systems. As countries seek to reduce greenhouse gas emissions, EVs have emerged as a key strategy in decarbonizing the transport sector, particularly when powered by clean electricity sources such as solar, wind, and hydro. While the pace and scale of adoption vary by region, countries like China, the United States, and several in Europe have made significant progress by aligning EV deployment with renewable energy expansion, supported by policies, technological innovation, and shifting public attitudes

2.4.1 International Trends in EV Adoption and Electricity Demand

China is currently the global leader in EVs adoption, with over 8 million EVs on the road as of 2023 and annual sales growth rates exceeding 80% in recent years; BEVs dominate the Chinese market, constituting the majority of new EV sales (Hossain et al., 2024; Tan et al., 2023). Europe follows closely, with countries such as Germany, Sweden, the Netherlands, and France demonstrating high adoption rates and robust growth, particularly in both BEVs and PHEVs. Germany surpassed one million EVs in 2022, while Norway continues to lead globally in market share, with over 80% of new vehicle sales being electric (Ruoso and Ribeiro, 2022; Tan et al., 2023).

The United States ranks as the third largest market, with over 2 million EVs in circulation and a growth rate of approximately 50% per year; BEVs dominate the segment, led by manufacturers such as Tesla (Hossain et al., 2024; Judijanto and Hildawati, 2025). In Southeast Asia, Thailand leads the ASEAN region with over 84,000 EVs, while Malaysia and Indonesia remain in earlier stages of adoption, with fewer than 31,000 and 10,000 EVs respectively. While BEVs are the most common, hybrid electric vehicles are also present (Abdullah et al., 2024). Looking ahead, China, Europe, and the United States are projected to remain dominant in the global EV landscape, with forecasts suggesting EVs could comprise 30–50% of new vehicle sales in these markets by 2030. The BEVs are expected to maintain their leading position due to ongoing advancements in battery technology and shifting consumer preferences (Hossain et al., 2024; Tan et al., 2023; Ruoso and Ribeiro, 2022).

The surge in EV adoption across global markets is attributed to a confluence of economic, environmental, social, and infrastructural factors. In China, rising gasoline prices have emerged as a key economic driver influencing the uptake of lower-cost and compact EV models as consumers seek to mitigate fuel-related expenses (Fei et al., 2024). Environmental considerations also play a critical role of increasing adaptation of EVs. Chao et al. (2022) reports that heightened awareness of air pollution and associated health risks motivates consumers especially in urban and affluent regions to transition toward cleaner transport alternatives. Wang et al. (2023) argued further that positive public sentiment toward environmental sustainability, captured through social media analytics, significantly correlates with increased EV adoption. Additional enablers include government subsidies, widespread charger availability, and growing price competitiveness of EVs relative to internal combustion engine vehicles (ICEVs). Ling et al. (2021) emphasized the importance of socio-demographic factors, showing that higher household income, prior exposure to EVs, and tailored policy incentives considerably elevate consumers' willingness to purchase EVs.

In Europe, Ruoso and Ribeiro (2022) found that higher per capita income levels, the integration of renewable energy into national grids, and persistently high fuel prices are strong predictors of EV market growth. Sociocultural dimensions such as urban density and pro-environmental norms also foster favorable conditions for EV adoption. Similarly, Tan et al. (2023) noted that the entry of competitively priced EV models, ongoing improvements in charging infrastructure and the expansion of battery manufacturing networks are pivotal to market expansion in both Europe and the United States. In the US context, this research group reported that brand leadership, particularly Tesla's effect, also contributes to the proliferation of EV model options, and growing consumer familiarity with EV technologies as primary contributors to sustained market penetration.

2.4.2 Global case studies on electric vehicle adoption impact on electricity demand

The rapid expansion of EV adoption is expected to substantially increase electricity demand, with varying implications across different regions. In the US, Powell et al. (2022) modeled the Western Interconnection and estimated that rapid EV adoption could increase peak net electricity demand by up to 25% under forecasted scenarios, and by as much as 50% in a full electrification stress test for 2035. In a comparative international projection, Ruoso et al. (2024) warned that without accelerated renewable energy generation, countries such as Australia and Canada may experience electricity demand surpassing supply by 2029 and 2031 respectively, requiring annual renewable electricity growth of at least 16.3 TWh in Australia and 18.1 TWh in Canada to remain sustainable.

In California, Ferdousee (2022) observed that EV adoption and associated charging infrastructure have already driven marked increases in residential and commercial electricity consumption. Similarly, Liang et al. (2022) found that EV-owning households consume approximately 0.4 kWh more electricity per hour compared to non-EV households; however, this increment can be more than offset up to 1.1 kWh per hour when home solar systems are integrated with EV charging. Muratori (2018) cautioned that uncoordinated residential charging could significantly reshape daily load curves and overload local distribution transformers, even at modest adoption rates. In line with this, Panossian et al. (2022) highlighted the risk of costly grid upgrades if charging behaviors remain unmanaged, though strategic planning and smart charging practices can alleviate much of this burden.

Similar concerns regarding the impact of electric vehicle (EV) integration on electricity grids are emerging across developing and transitional economies. In Dubai, Elghanam et al. (2022) emphasized the importance of advanced demand modeling to inform infrastructure planning, given the complex relationship between EV trip patterns and localized grid loads. In Pakistan, Nadeem et al. (2021) projected that electrifying 90% of two- and four-wheel vehicles by 2040 could result in an annual EV electricity demand of 14.7 TWh, requiring an estimated 9 GW of additional solar photovoltaic capacity alongside significant grid reinforcement. Similarly, Abd et al. (2024) forecast that EV adoption in Malaysia could increase peak electricity demand to nearly 55,000 MW by 2050, compared to 34,000 MW in a baseline scenario without EVs, highlighting the critical need for grid modernization and integration of renewable energy sources. Comparative analysis by Ruoso et al. (2024) further reinforced these findings, cautioning that without proactive renewable energy expansion, countries such as Brazil, Canada, and Australia may encounter substantial energy security challenges. However, Vithayasrichareon et al. (2015) demonstrated that in Australia, coordinated EV charging strategies especially those aligned with solar PV output could alleviate grid stress and reduce emissions from the electricity sector. In Costa Rica, Gómez-Ramírez et al. (2024) reported that high EV penetration beyond 2030 could trigger voltage drops and demand surges, necessitating major investments in transmission and distribution infrastructure to uphold system reliability.

2.4.3 Sustainable Energy Integration for EV Charging

A substantial body of research confirms that EVs deliver significant environmental benefits only when integrated with low-carbon electricity sources, particularly solar and wind. Kobashi et al. (2020) demonstrated that coupling rooftop photovoltaic (PV) systems with EVs in cities like Kyoto and Shenzhen especially in vehicle-to-home (V2H) configurations can reduce CO_2 emissions by up to 74% compared to conventional grid charging. Similarly, Ghosh (2020) emphasized that the net GHG reduction potential of EVs is heavily dependent on the carbon intensity of the electricity mix, warning that fossil fuel-based grids significantly undermine decarbonization outcomes. Daramola et al. (2023) illustrated that integrating renewables and battery storage with EV charging not only lowers CO_2 emissions by nearly 48% but also reduces long-term operating costs. Reinforcing this, Wang et al. (2023) found that carbon-responsive charging strategies where EVs are charged during periods of low grid carbon intensity can cut EV-related emissions by up to 32.7%, making charging behavior a critical variable in climate impact mitigation. Reddy et al. (2024) and Pan and Shittu (2025) further argued that the full decarbonization benefits of EVs materialize only when supported by a renewable-dominated power mix, underscoring the importance of aligning policy, infrastructure, and energy planning with sustainable charging practices.

Recent international case studies provide practical evidence of successful EV and renewable energy integration. AlAhmad et al. (2025) developed a planning framework that optimally coordinates wind, solar PV, battery storage, and EV charging systems, significantly improving green energy penetration and system efficiency. In Okinawa, Japan, Masrur et al. (2022) reported that microgrids incorporating EVs with PV, battery storage, and combined heat and power (CHP) units enhance both economic performance and grid resilience, particularly during outages. Barman et al. (2023) documented how global smart charging strategies are helping countries manage the dual challenge of EV proliferation and renewable energy variability, focusing on energy storage, standardization, and smart grid technologies. Monteiro et al. (2025) observed that integrating battery energy storage systems (BESS) with high-speed chargers, as seen in Brazil’s E-Lounge initiative, substantially increased charging sessions while stabilizing the grid. In Europe, Štogl et al. (2024) emphasized that vehicle-to-grid (V2G) systems enhance flexibility by allowing EVs to serve as distributed energy resources, while Kumar and Rajan (2023, in press) showed that hybrid PV–wind systems with advanced control architectures can support high-efficiency, stable, and scalable EV charging. Complementing these findings, Çelik et al. (2025) highlighted the critical role of energy storage and intelligent management in enabling large-scale, grid-friendly EV integration, and Ahmad et al. (2025) called for multi-energy systems that align EV deployment with sustainable mobility goals.

2.5 EV Adoption and Renewable Energy Potential in African Nations

The EV adoption in African nations remains in its infancy, but the continent possesses considerable potential for growth, particularly when coupled with its rich renewable energy resources. Currently, the pace of EV uptake is slow, constrained by a range of structural challenges such as high upfront costs, limited charging infrastructure, unreliable electricity supply, and regulatory gaps. These barriers are particularly evident in countries like South Africa, Nigeria, Kenya, and Ghana (Okoh and Onuoha, 2024; Ayetor, 2022). Nevertheless, future projections suggest a promising trajectory: Ajao et al. (2024) estimate that EV sales in leading Sub-Saharan African nations could exceed 700,000 units within five years, contingent on the implementation of robust infrastructure and supportive policies.

The HEVs currently dominate the market in Africa, with only a few countries demonstrating readiness for large-scale EV deployment, largely due to superior infrastructure and regulatory environments (Ayetor, 2022). The reliance on fossil-fuel-based grids, however, threatens to undermine the environmental promise of EVs. To ensure sustainability, integrating renewables such as solar, wind, and biogas into EV charging systems is critical (Ampah et al., 2022; Ibrahim et al., 2021). For instance, Ampah et al., 2022 presented a case study from Ghana where hybrid biogas-photovoltaic systems for EV charging and hydrogen refueling and found that it is both technically viable and economically beneficial, significantly reducing GHG emissions while contributing to SDGs.

The mismatch between renewable energy potential and current grid reality remains a major constraint across the continent. Ibrahim et al. (2021) observe that despite the abundance of renewable resources in countries like Nigeria, Cameroon, Ghana, and South Africa, their energy sectors remain dominated by fossil fuels due to policy inconsistencies, high tariffs, and infrastructural limitations. Financial barriers further exacerbate the problem. Sweerts et al. (2019) emphasize that high financing costs deter investment in clean energy infrastructure, though targeted financial de-risking could enable solar PV alone to meet up to 15% of Africa’s electricity demand by 2050 even in the absence of climate-specific policy.

Empirical findings also support the view that the dual pursuit of EV adoption and renewable integration yields greater sustainability outcomes. Sahoo et al. (2024) provided evidences cross the countries, including South Africa, showing that the combined deployment of EVs and renewable energy has a more significant impact on reducing carbon and ecological footprints than either strategy alone. Agyekum et al. (2023) carried out SWOT analysis on alternative fuels and EVs in Africa, and highlighted the declining cost of renewable technologies and increased climate awareness as critical opportunities for scale-up. However, they also pointed out to persistent threats, including weak regulatory frameworks, limited access to funding, and the continued dominance of imported used internal combustion engine vehicles.

Government-led strategies at the country level provide concrete approaches to overcoming challenges in electric vehicle adoption and energy system development. In South Africa, Akintayo et al. (2024) underscore the importance of local EV production, renewable-powered charging infrastructure, and tax incentives. They further argue that government-led training and local manufacturing capacity could accelerate adoption rates. Ajao et al. (2025), applying a modified Unified Theory of Acceptance and Use of Technology (UTAUT), concluded that infrastructure quality, policy consistency, and favorable market dynamics are the most influential factors shaping EV adoption intentions in Sub-Saharan Africa. Similarly, Ayetor (2022) stresses the need for government incentives, skilled labor development, and standardized infrastructure to support the transition from conventional to electric mobility.

Okoh and Onuoha (2024) advocate for a shift in investment priorities away from fossil fuel infrastructure toward renewable energy systems to support efficient EV adoption. They call for the establishment of comprehensive regulatory frameworks and accessible financing models. Reinforcing this argument, Ampah et al. (2022) discussed how hybrid renewable systems can deliver both environmental and economic benefits, thus validating the technical and policy case for integrated clean mobility strategies in Africa.

2.6 Sustainable Energy and Electric Vehicles in Kenya

Kenya presents a unique opportunity for aligning EV adoption with sustainable energy development, given its high share of renewables in the electricity mix mainly from geothermal, hydro, wind, and solar sources. The country's ongoing electrification efforts, combined with government support for clean mobility, position it well for a green transport transition. However, realizing this potential requires overcoming barriers such as limited charging infrastructure, high upfront EV costs, and policy coordination gaps. This section explores how Kenya's renewable energy landscape can support widespread EV adoption and what institutional, technical, and economic adjustments are needed to ensure a sustainable and resilient transport-energy nexus.

2.6.1 Electric Vehicles in Kenya

The EV growth in Kenya is still at an early stage but shows promising potential. According to Mwangi et al. (2025), Kenya's EV ecosystem is developing, with ongoing efforts to address policy and supply chain barriers. Njenga and Opiyo (2023) highlight that the two- and three-wheeler public transport segment is expanding rapidly, growing about three times faster than conventional vehicles, and represents a key opportunity for electrification. However, the current market penetration remains low, and challenges such as high upfront costs, limited charging infrastructure, and knowledge gaps persist (Mani and Maina, 2024). Overall, while Kenya's EV market faces notable obstacles, targeted policies and investments could accelerate growth and help realize the country’s electrification potential.

Kenya’s policy landscape has been instrumental in catalyzing the growth of EVs, with a suite of fiscal, regulatory, and strategic interventions designed to promote adoption while aligning with the country’s climate and energy goals. Mwangi et al. (2025) highlight that the government has implemented tax exemptions, reduced import duties, and national e-mobility strategies that collectively aim to lower entry barriers and incentivize both private and commercial investment in EV technologies. Notably, targeted policies have focused on the two- and three-wheeler transport segment, which constitutes a significant share of urban mobility. Njenga and Opiyo (2023) report that pilot programmes and regulatory frameworks for electric motorcycles have seen initial success, particularly in cities where air pollution and transport-related emissions are most severe.

Despite these gains, significant barriers persist. According to Mani and Maina (2024), challenges such as high upfront vehicle costs, inadequate charging infrastructure, and limited public awareness continue to hamper widespread adoption. They argue for the expansion of financial incentives and awareness campaigns to close these gaps. Complementing these efforts, Kenya’s robust renewable energy mix dominated by geothermal, hydro, and wind provides an ideal backdrop for clean mobility. However, Rotich et al. (2024) caution that outdated energy regulations and slow implementation threaten to undermine the effectiveness of EV-supportive policies. Overall, while Kenya’s evolving policy framework lays a solid foundation for EV growth, sustained momentum will depend on coordinated reforms, institutional strengthening, and deeper integration between energy and transport planning.

2.6.2 Kenya's Sustainable Energy Potential

Kenya has made significant strides in developing a diverse and sustainable energy portfolio. The country's energy mix is dominated by renewable sources, with wind, solar, hydroelectric, and geothermal power playing central roles in national development and climate mitigation strategies. Together, these sources account for about 91% of Kenya’s electricity generation (KNBS, 2024). Grid capacity forecasts for 2040 suggest possible expansion to 4,763 MW (low scenario), 6,638 MW (reference), and 9,790 MW (vision), where geothermal, wind and solar are prioritized for their abundance (Rotich et al., 2024; Manirambona et al., 2022.)

The country has an estimated wind power potential of over 3,000 MW, concentrated in Turkana, Marsabit, Ngong, and coastal regions where wind speeds exceed 9 m/s ((International Trade Administration, 2024). As of 2024, wind contributed about 434 MW, or 13.3% of Kenya’s 3,264 MW renewable capacity (Kimutai et al., 2024). The Lake Turkana Wind Power project (310 MW) remains Africa’s largest, while the Ngong Wind Farm (75.5 MW) demonstrates viability under supportive policies (Kazimierczuk, 2019; Ongoma, 2018). Together with the favorable wind speed distribution shown in Figure 2.4, these milestones highlight the sector’s strong potential for expansion. Future developments include the proposed Kipeto Wind Farm (100 MW) and expansions at existing high-potential sites. However, projects like the Kinangop Wind Park have faced delays due to land use and community opposition (Kazimierczuk, 2019). Despite Kenya’s vast wind resource, only 7.3% is currently utilized, and significant barriers remain particularly in grid integration, financing, and local acceptance (Rotich et al., 2024). Notably, hybrid wind-solar systems are being tested for off-grid rural electrification, indicating promising avenues for improving energy access in underserved regions (Mulumba and Farzaneh, 2023). Overall, while wind energy offers high potential, its success will depend on targeted investment, robust infrastructure, and continued policy support.

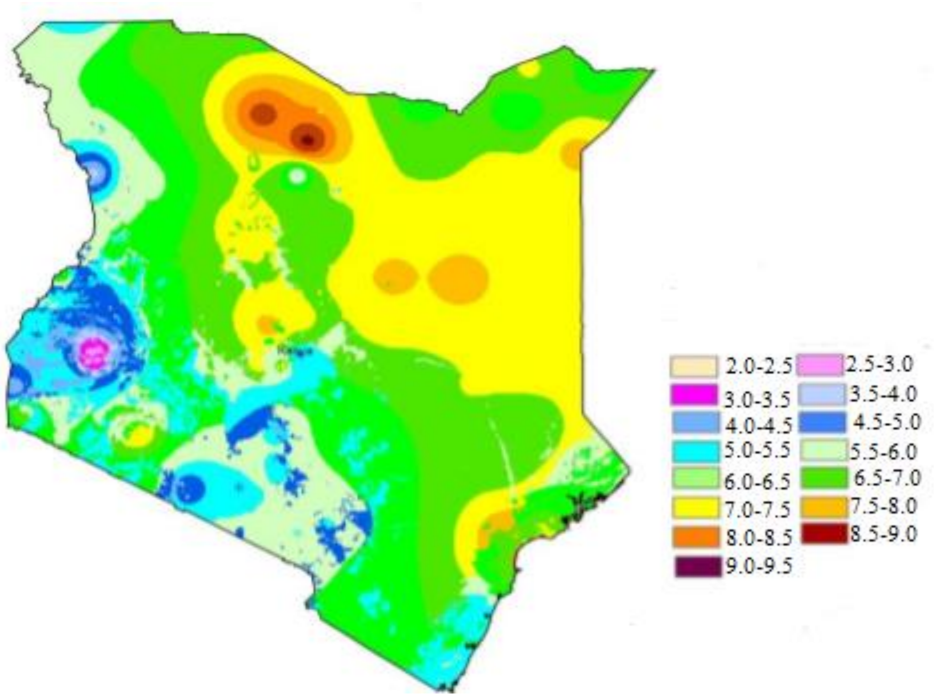

Figure 2. 4: Wind speed at 100 m height. (WinDForce Management Services Private Limited-Kenya, 2013)

Kenya possesses vast solar energy potential estimated at 15,000 MW, driven by high solar irradiance averaging 4–6 kWh/m²/day across most regions, with arid counties such as Turkana and Marsabit recording values of up to 7 kWh/m²/day (EPRA, 2024). The country's equatorial location ensures stable solar availability with minimal seasonal variability, offering predictable conditions that make solar energy a highly reliable option for large-scale investment (Oloo et al., 2015; Kariuki and Sato, 2018)). As shown in

Figure 2.5, these favorable radiation levels position solar power as one of the most promising renewable energy resources for Kenya's future electricity mix.

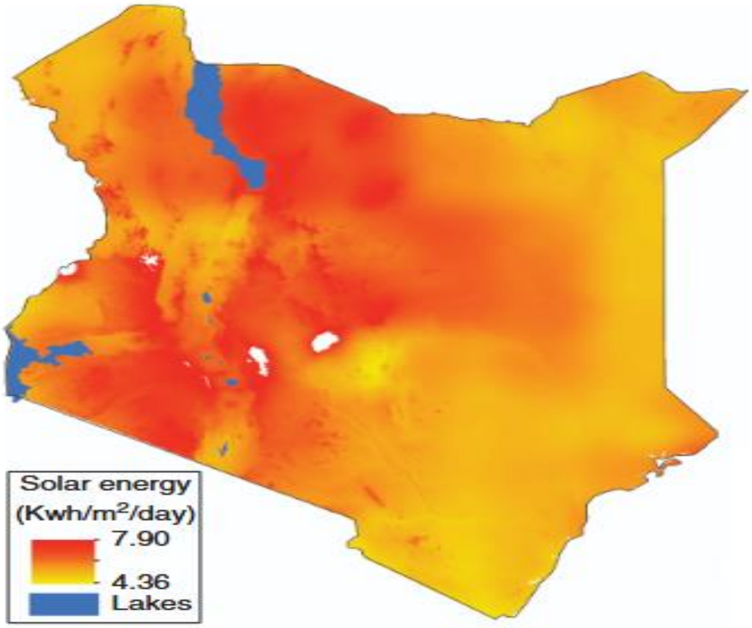

Figure 2.5: Spatial variation of solar energy potential in Kenya (Oloo, 2015)

Currently, solar contributes about 7.4% or 241 MW of the national renewable energy capacity, yet its utilization remains low, at just 1.6% of its estimated technical potential (Kimutai et al., 2024). Case studies, including the 600 kWp Strathmore University rooftop system and the 180 kWp Timau installation, Kesses 1 Solar PV Park, Garissa Solar Power Station, Malindi Solar Power Station, Eldosol Solar Power Station, Radiant Solar Power Station, Rumuruti Solar Power Station, Kopere Solar PV Park (Voltalia), Bavinci Africa Solar Project, HDF Green Hydrogen Solar PV Project, KenGen Floating Solar Power Station, KOSAP (Kenya Off-Grid Solar Access Project) and GivePower Solar Water Desalination Plant (Kiunga) demonstrate that solar performance in Kenya aligns with global standards in terms of efficiency and output (Ayora et al., 2023). Spatial suitability models indicate that up to 70% of Kenya's land is viable for solar deployment, with Turkana and Marsabit counties identified as ideal for large-scale projects (Oloo et al., 2015; Gathu et al., 2017). Solar energy is expected to play a pivotal role in the ongoing expansion of renewable capacity to nearly 4,000 MW, with additional growth projected under the 2040 scenarios (Kimutai et al., 2024; Rotich et al., 2024). Despite the strong resource base and growing technical readiness, the literature emphasizes the need for policy consistency, financial innovation, and business model adaptation especially in off-grid and mini-grid markets to fully leverage Kenya's solar potential (Adwek et al., 2019).

Hydroelectric power has historically been central to Kenya's electricity generation, currently accounting for around 25.5% of installed capacity approximately 830 MW although its actual contribution to the energy mix has declined to about 10.7% due to seasonal rainfall variability and climate change impacts (Kimutai et al., 2024; Keter and Kiplagat, 2024). Key hydro stations are located along the Tana River (e.g., Kindaruma, Gitaru, Masinga, Kamburu, and Kiambere) and at the Turkwel Gorge (Kimutai et al., 2024). While upgrades to existing facilities and new small- to medium-scale projects are underway, energy policy envisions a gradual reduction of hydro's share to about 5% by 2030, as more climate-resilient technologies like solar, wind, and geothermal are scaled up (Gumbe and Kola, 2023). Despite environmental limitations, hydropower remains valuable for grid stability and rural electrification, with evaluations showing strong performance in supply quality and operational efficiency (Amolo et al., 2024; Keter and Kiplagat, 2024). However, key challenges include affordability, drought-related volatility, and financing constraints, particularly due to long development timelines and the need for credit enhancement mechanisms (Amolo et al., 2020; 2021). Thus, while hydro will remain a foundational element of Kenya's energy mix, its strategic role is shifting toward complementary, rather than primary, generation.

Kenya is Africa's leading geothermal producer and ranks among the top ten globally, with an installed capacity of approximately 889 MW and a technical potential exceeding 10,000 MW (Rotich et al., 2024; Sharouda et al., 2024). The main s of development include the Olkaria complex, Menengai and Eburru fields, with new prospects under exploration at Baringo-Silali, Suswa and Longonot (Ng'ethe and Jalilinasrabady, 2023; Kimutai et al., 2024). As illustrated in Figure 2.5, these geothermal resources are clustered along the Rift Valley, which has enabled Kenya to integrate geothermal as a reliable baseload option within the national grid (Rotich et al., 2024). Despite this progress, expansion has raised several environmental and social concerns, including surface disturbance, waste management, and localized emissions (Rotich et al., 2024), alongside disputes over land rights, resettlement, and benefit sharing in affected communities (Klagge et al., 2020).

Broader constraints such as high upfront capital costs, limited technical expertise, and inadequate political prioritization also hinder full exploitation of the resource, underscoring the importance of safeguards, improved financing, and stronger local capacity (Abdi et al., 2024). Beyond electricity production, geothermal direct-use potential remains largely untapped, with over 150 hot springs offering a combined thermal capacity exceeding 275 MWt for applications in aquaculture, greenhouse heating, and tourism (Ng'ethe and Jalilinasrabady, 2023).

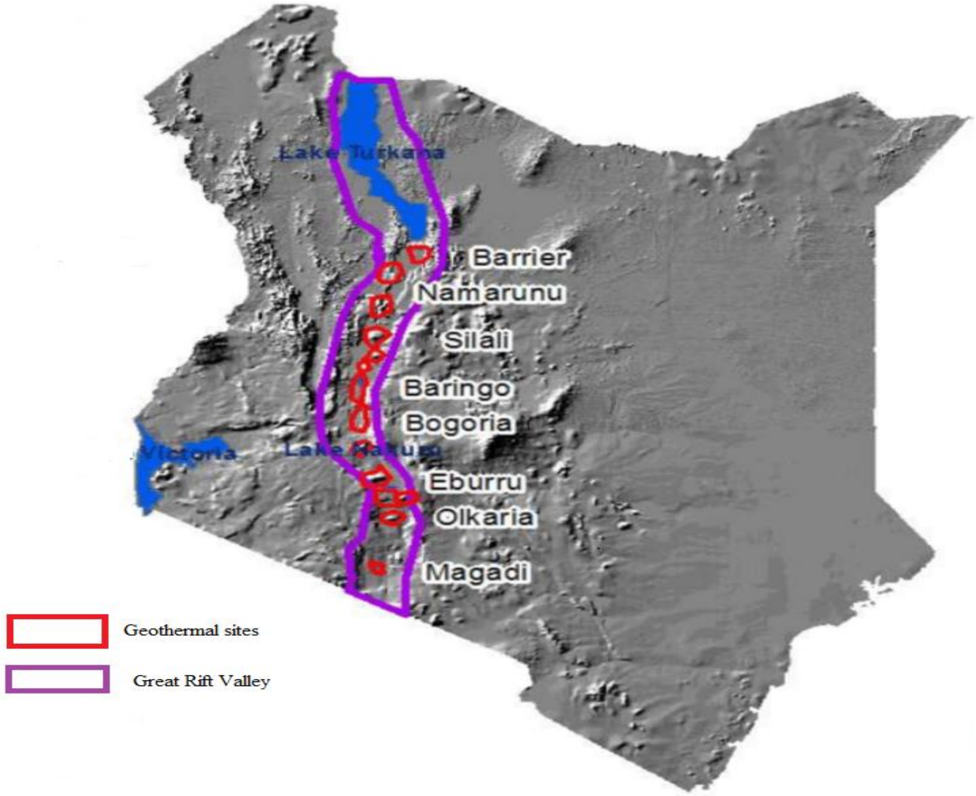

Figure 2.6: Kenya’s geothermal cites (Kuria, 2017)

2.6.3 Electricity Demand in Kenya

Electricity demand in Kenya has been rising steadily, driven by rapid population growth, increased electrification, and economic development. Manirambona et al. (2024) reported that the residential sector is projected to remain the largest consumer of total final energy, accounting for nearly 80% of demand by 2040, though much of this is still met by biomass, with electricity mainly used for lighting. Despite significant progress in electrification reaching nearly 77% of the population by 2022, but actual household electricity consumption, especially in rural areas, remains low due to affordability issues, cultural factors, and continued reliance on traditional fuels (Rotich et al., 2024;

Tesfamichael et al., 2020). Mabea (2014) found that residential electricity demand is positively linked to income growth, with a long-run income elasticity of 0.1, suggesting that as household incomes rise, electricity use will increase gradually. Several studies have also highlight that while access to electricity is expanding, stimulating higher and more sustainable household consumption remains a challenge, as many households are cautious about costs and use electricity mainly for basic needs (Tesfamichael et al., 2020). Projections indicate that total electricity demand will continue to grow, but the pace and scale will depend on improvements in affordability, infrastructure, and the transition from biomass to modern energy sources.

Kenya's commercial and industrial sectors are the largest consumers of electricity, together accounting for over 70% of national demand, with demand in these sectors being highly income correlated with economic growth and further influenced by electricity prices, efficiency improvements, and supply-side factors such as hydro inflows, according to Njeru et al. (2020). The industrial sector alone is responsible for about 50% of electricity consumption and has experienced a consistent annual growth rate of 4% in energy demand from 1990 to 2021, with further increases projected through 2030 (Kimutai et al., 2025). As of 2024, Kenya's installed electricity generation capacity has surpassed 3,000 MW, with the grid expanding to meet rising demand (Rotich et al., 2024). Future projections using advanced modeling approaches suggest that total national electricity demand could reach 25,000–30,000 GWh by 2035, with the commercial and industrial sectors remaining key drivers (Kihara et al., 2024). By 2040, total electricity demand could rise to 57,400 GWh under ambitious development scenarios (Kehbila et al., 2021). However, Waswa et al. (2024) cautioned that official forecasts may be overstated, emphasizing the need for regular updates and more accurate modeling. Kenya’s commitment to a high share of renewables in its generation mix, alongside targeted policies for energy efficiency and grid reliability, will be crucial for meeting the growing and evolving needs of these sectors (Rotich et al., 2024; Fields et al., 2023).

Although traditional sectors are well understood, emerging demand from EVs remains unquantified. Kenya has initiated its transition to e-mobility through policy incentives, private investment, and global decarbonization trends (Ajao et al., 2024), but EV usage has yet to be integrated into electricity demand forecasts. This new sector introduces challenges such as variable charging patterns, localized peak loads, and grid stress (IRENA, 2022). Data on vehicle kilometers traveled (VKT), average EV energy consumption, and charging behavior in Kenya are limited, making it difficult to determine the scale and timing of new electricity demand (Rotich et al., 2024). As a result, electrified transport could significantly reshape Kenya’s electricity demand profile in the near future, necessitating assessment of whether sustainable energy resources can sufficiently support this expansion.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter outlines the methodology employed in this study in order to explore the level of penetration of EVs vis-a-vis ICEVs in the transportation industry in Kenya and present insight into the future mobility based entirely on the EVs and the potential of the country to exclusively power them from the sustainable energy resources.

3.2 Research Design

The study employed a mixed-methods design, integrating both quantitative analysis and qualitative insights. The quantitative component focused on analyzing data on vehicle registrations and energy demand, while the qualitative component involved gathering expert opinions and insights through interviews and surveys.

3.3 Data Collection

Data on vehicle registrations from 2010 to the present was collected from the Kenya National Bureau of Statistics (KNBS) and the National Transport and Safety Authority (NTSA). This data included the number of electric vehicles (EVs) and internal combustion engine vehicles (ICEVs) registered annually. Additional information was sourced from industry reports and government publications.

Primary data was collected through surveys and interviews with EV owners. The surveys gathered information on the available charging infrastructure, charging times, and the driving range (autonomy) for a full battery charge. Technical specifications were also reviewed from EV manufacturers.

Secondary data on the potential of Kenya's sustainable energy resources such solar, wind, geothermal, and hydro was obtained from KNBS, the Ministry of Energy, Kenya Power, and other relevant agencies. This data included current energy production levels, planned capacity expansions.

3.4 Data Analysis

Time series analysis was conducted on the historical vehicle registration data to determine the growth rates of EVs compared to ICEVs. Regression models were employed to analyze trends and project future growth rates under different scenarios. This was achieved using analysis tools such as excel.

The survey and interview data were analyzed using descriptive statistics to summarize the charging processes, infrastructure availability, and driving ranges of existing EVs in Kenya. Qualitative analysis was used to interpret the challenges and opportunities related to EV charging.

The growth rates derived from historical data were used to project the number of EVs in Kenya by 2063. Logistic growth models were applied to estimate future adoption rates under various. This model has been widely recognized as a suitable framework for analyzing the adoption of new technologies because it captures the characteristic S-shaped diffusion pattern observed in many markets. Adoption typically begins slowly with innovators, accelerates rapidly as the early majority enters the market, and eventually slows as saturation is approached. This "slow–fast–slow" trajectory has been documented in the diffusion of mobile phones in Africa (Aker and Mbiti, 2010), the spread of internet access worldwide (Greenstein and McDevitt, 2011), and more recently the uptake of electric vehicles in both developed and emerging markets. Lieven and Rietmann (2020) applied the logistic model to project the trajectory of electric mobility across 26 countries, demonstrating its robustness in forecasting global EV adoption patterns. Castro et al. (2022) further confirmed the applicability of the logistic growth method by using it to forecast energy demand for electric vehicle fast charging stations integrated with solar photovoltaic systems. Thus, the LGM utilized in this study is based on the equation developed by Castro et al. (2022).

$$E(t) = \frac{L}{1+\left(\frac{L-E_0}{E_0}\right)e^{-kt}} \tag{3.1}$$

where $E(t)$ is the number of vehicles at any time t, L is the saturation limit (i.e., maximum value that E(t) can reach), E_o is the initial vehicle population at time t = 0 and k is the growth rate parameter. The detailed derivation of Equation (3.1) is presented in Appendix I.

By fitting the ICEV registration data into Eq. (3.1), the parameters L and k were estimated using MATLAB software, followed by development of three scenarios to explore different pathways of replacement of ICEVs with EVs for the year 2063. These scenarios encompassed original (100%), optimistic (75%), moderate (50%) and conservative (25%) adoption rates to project the EV uptake (Lieven and Rietmann, 2020). The logistic growth model assumes that EV adoption follows an S-shaped curve limited by a maximum feasible population L, with a constant initial population E_o and growth rate k over the projection period. The model considers historical trends indicative of future growth and does not explicitly account for sudden economic shocks, policy changes, or technological breakthroughs, while providing a realistic framework for scenario analysis under typical market conditions.

The four scenarios were developed based on Kenya’s current EV market conditions, including registrations, supportive policies, and persistent barriers. EV registrations doubled from 2,694 in 2023 to 9019 by the end of 2024, mostly electric motorcycles (Musau, 2025), facilitated by reductions in excise duty and VAT exemptions (Automag, 2025). Nevertheless, high upfront costs, limited charging infrastructure, and low public awareness continue to constrain adoption (Kiprono, 2025). These structural conditions were used to define the scenario percentages whereby the 25% scenario reflects uptake achievable under current, moderately favorable conditions primarily driven by early adopters, the 50% and 75% scenarios assume improvement in infrastructure, awareness campaigns, and policy incentives that enable adoption by the early and late majority while the 100% scenario represents full market saturation under optimal conditions with widespread acceptance. By linking Kenya’s current challenges and supportive policies to DOI categories, the scenarios provide a structured and realistic basis for projecting EV adoption under varying conditions.

The projected electricity demand for EVs in 2063 was calculated based on the estimated number of EVs and their energy consumption per vehicle. The total energy demand by a fleet of EVs, E_{EV} is given by the following equation (Gryparis *et al.*, 2020):

$$E_{EV} = N_{EV} \times d_{an} \times C_b \tag{3.2}$$

where N_{EV} is the total number of EVs in the projected year, d_{an} is the average annual mileage and C_b is the average consumption per kilometer in a given scenario. The GIZ (2019) data gives d_{an} = 17000 km and C_b = 0.2 kWh/km.

The electricity demand at the charging point, E_{ch} can be calculated from the following equation (Gryparis *et al.*, 2020):

$$E_{ch} = \frac{E_{EV}}{\varphi_{ch}} \tag{3.3}$$

where φ_{ch} is the average efficiency of the charging system. Eq. (3.3) gives amount of electricity required at the charging port, and excludes transmission and distribution losses. The net electricity, E_{net} at the site of charging depends on both electricity demand, E_{ch} given by Eq. (3.3) and the annual transmission and distribution losses, E_{loss} and is given by:

$$E_{net} = \frac{E_{ch}}{E_{losses}} \tag{3.4}$$

Therefore, combining Eq. (3.3) and (3.4) gives net electricity to be generated as:

$$E_{net} = \frac{E_{EV}}{\varphi_{ch}(1 - E_{losses})} \tag{3.5}$$

Eq. (3.5) gives the electrical energy generation required to meet the electrical energy demand of EVs. The transmission and distribution losses in Kenya are very high averaging at 21.2% of the total electricity generated annually (KNBS, 2024).

The projected electricity demand from domestic and industrial consumers in 2063 was based on consumption data for the period 2010 to 2024 from KNBS as recorded in **Table A1** (Appendix II) and plotted in **Figure 3.1**. The best lines of fit are linear with high R^2 values of 0.9479 and 0.9576 respectively for domestic and industrial sectors and their corresponding regression equations are:

$$E_{Industrial} = 156.52t - 311411 \tag{3.6}$$

And,

$$E_{Domestic} = 179.17t - 357480 \tag{3.7}$$

These equations will be used to project the electricity demand from the two sectors.

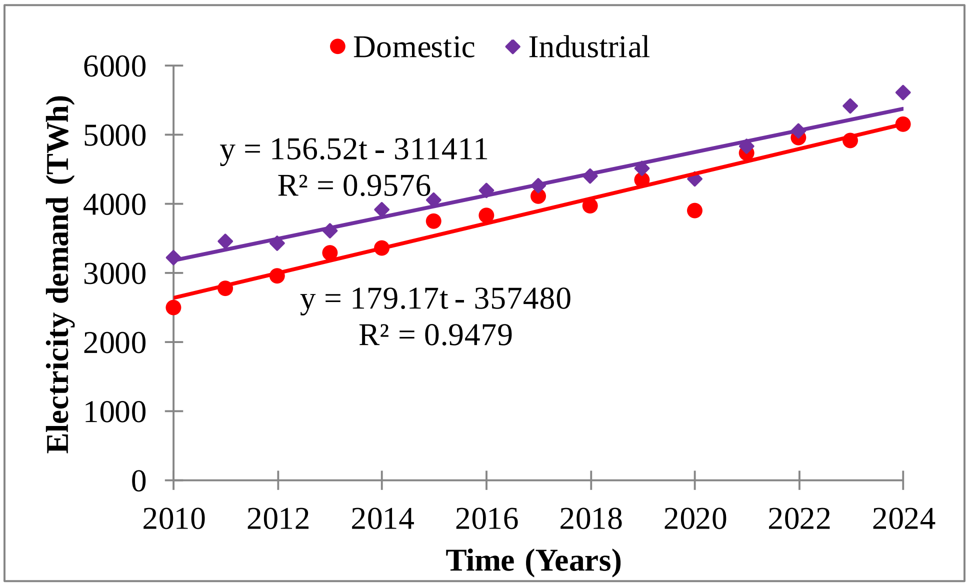

Figure 3. 1: Domestic and Industrial electricity demand from 2010 to 2024

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings of the study and provides a detailed discussion of the results in relation to the research objectives outlined in Chapter 1. The results are presented using graphs, tables, and descriptive analysis to address the three (3) specific objectives of the study.

4.2 Growth Rate of EVs vs. ICEVs from 2010 to 2024

4.2.1 Trends in EV and ICEV Registrations

Figure 4.1 presents the number of vehicles registered per year in Kenya from 2010 to 2024, for both ICEVs and EVs. The data used to plot these graphs are given in **Table A2** (Appendix III).

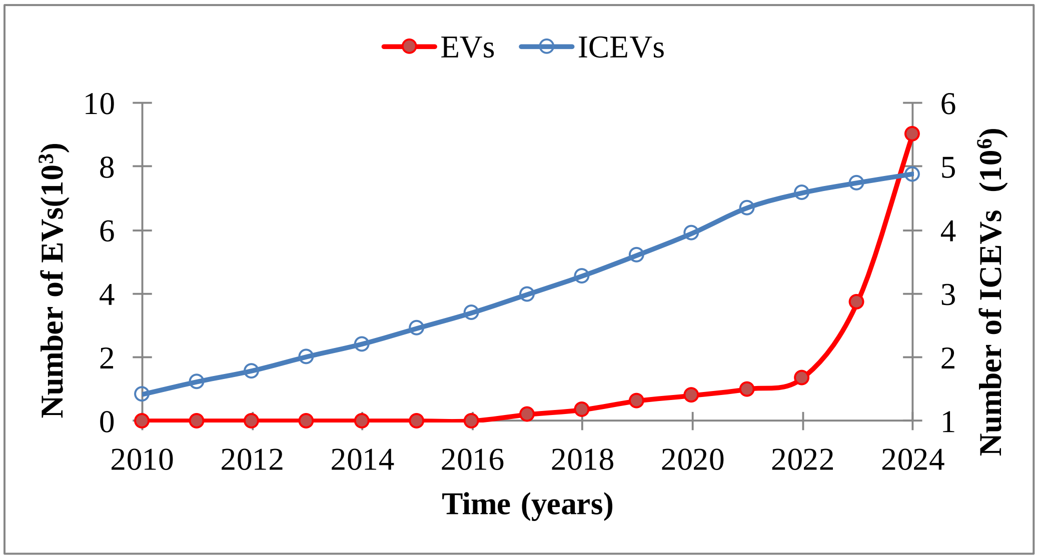

Figure 4. 1: Trend of growth of ICEVs and EVs in Kenya's from 2010 to 2024

The results in **Figure 4.1** show that the number of ICEVs in Kenya has increased steadily from approximately 1.4 million in 2010 to nearly 4884057 units in 2024, implicating an increased consumption of on conventional fossil fuel for transportation sector, hence proportionate increase in CO_2 emission. In contrast, EVs were entirely absent from the national vehicle stock until 2016, when the first EV was registered and thereafter grew steadily to 1350 units in 2021 followed by abrupt increase to 9019 by 2024. Considering total vehicles registered in the country in 2024, EVs constitute paltry 0.02%, hence very insignificant. The era of EVs in Kenya begun effectively in 2016, just one year after SDGs were rolled out in 2015. The sharp increase between 2021 to 2024 can be attributed to the growing awareness on the environmental and climate issues by the members of public and the need to curb it, government incentives through policy intervention, diversity of EVs (especially electric motor cycles), gradual improvements in charging infrastructure and continual rise in prices of petroleum fuels.

4.2.2 Projections of EV Fleet by 2063

The results in **Figure 4.1** were replotted but with independent variable (i.e. years) itemized beginning with 2017 as the first (1) year which marked the start of consistent EVs registration in Kenya. This was done to get appropriate regression equations that could describe the growth of both types of vehicles for purposes of estimating the number of vehicles, particularly EVs, registered in Kenya by the year 2063. The resulting graphs are given in **Figure 4.2**. From these results, the best regression equations for both ICEVs and EVs are third order polynomials given respectively by:

$$\#\mathrm{IC}EVs = -4762.7t^3 + 49180t^2 + 182477t - 3 \times 10^6 \qquad (4.1)$$

And

$$\#EVs = 99.194t^3 - 1018.3t^2 + 3189.1t - 2312.2 \qquad (4.2)$$

where t is time in years. The R^2 values for these regression equations are very high at 0.9989 and 0.9874 for ICEVs and EVs respectively. Using equation (4.2), the projected number of EVs will be 8196769 by the year 2063.

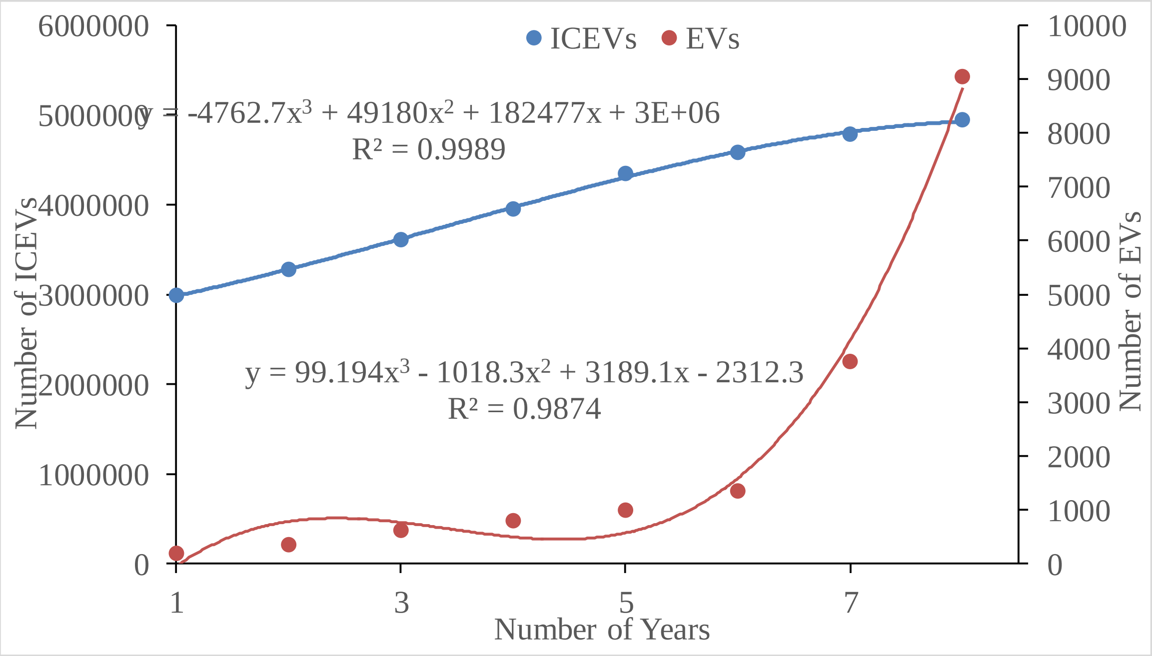

Figure 4. 2: Trend lines of growth of ICEVs and EVs in Kenya's from 2017 to 2024

Figure 4.3 presents the modeling results obtained from LGM forecasting of EVs adoption in Kenya based on historical ICEVs data from 2010 to 2024. The forecasts were implemented in MATLAB, with the growth parameters L and k determined using the code provided in Appendix IV. These parameters were then applied in Equation (3.1) to calculate the projected EVs adoption, and generated data are tabulated in **Table A3** (Appendix V). In 2063, the predictions of EVs adaptation are respectively 5087062, 9246810, 10795415 and 11122187 conservative (25%), moderate (50%), optimistic (75%) and original (100%).

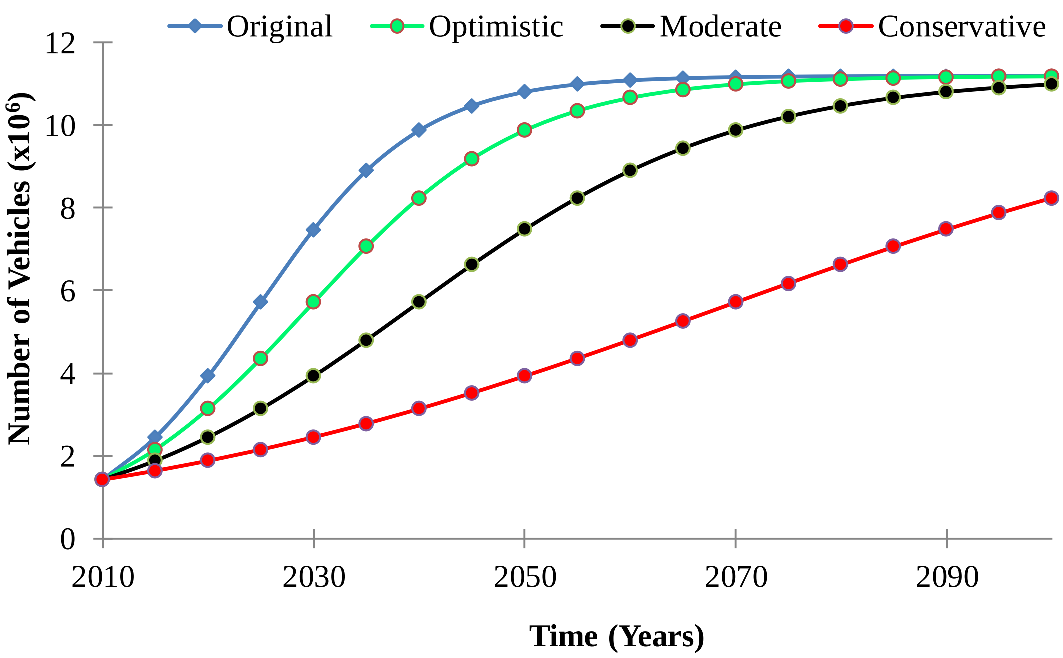

Figure 4. 3: EV adoption projection using LGM

Comparing the projection results from Figures 4.2 and 4.3, the prediction of EVs in 2063 by regression analysis is 8196769, hence lies between the conservative of 5087062 and moderate of 9246811 from LGM prediction. Therefore, with reference to regression analysis, the conservative scenario underestimates projected number by an absolute value of 3109706 or 37.9%, while moderate scenario overestimate by absolute value of 1050042 or 12.8%. This shows that projection from moderate scenario closely matches that from regression analysis, hence the expected number of EVs by 2063 lies between 8196769 and 9246811.

4.2.3 Growth per Vehicle Type

Figure 4.4 presents the results on the distribution of ICEVs based on the vehicle category during the reporting period. The data used to plot it is given in **Table A4** (Appendix VI).

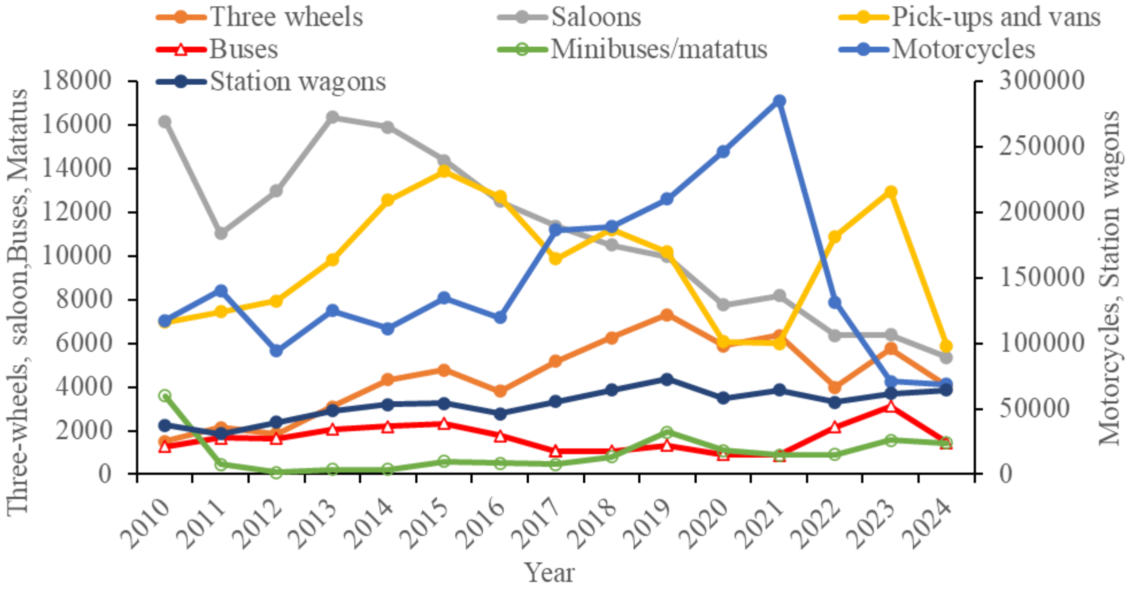

Figure 4. 4: Trend of ICEVs growth per category in Kenya's from 2010 to 2024.

From **Figure 4.4**, motorcycles exhibit the most significant variation, with registrations rising from 117266 units in 2010 to a peak of 285203 in 2021, reflecting their increasing role in informal transport and delivery services. However, registrations declined sharply thereafter, falling to 70691 units in 2023 and 64204 in 2024, largely due to post COVID-2019 pandemic, market adjustments and rising acquisition costs. Three-wheeled vehicles also grew steadily, from 1521 in 2010 to a peak of 7322 in 2019, and thereafter generally declined to 4064 in 2024.

Further, **Figure 4.4** shows an initial decline in ICEV saloons from 16165 units in 2010 to 11026 units in 2011 followed by gradual growth to 16343 in 2013 and thereafter gradual decline to 5367 by 2024. Pick-ups and vans grew gradually from 6975 units in 2010 to 13878 units in 2015, and then gradually declined to 5986 units in 2021, thereafter rose to 12957 units in 2023 and finally dropped abruptly to 5879 units in 2024. Buses and minibuses remained to be one of the least registered category among the ICEVs and demonstrated a fluctuating increase from 2010 and peaking modestly at 3122 in 2023 and dropping to 1452 units in 2024. The minibuses registered in 2010 were 3600, but then dropped to a low of 78 units registered in 2012, before gradually increasing to 1932 in 2019 followed by a slight decline to 882 units in 2021 and thereafter registered a gradual growth to 1441 units in 2024. Finally, the number of station wagons registered in 2010 were 37553, though initially decreased to 31119 in 2011, showed gradual growth in the number of registered to a peak of 72512 units, thereafter declined slightly to 64204.

Figure 4.5 presents the distribution of registered EVs by category in Kenya, and the data used to plot it is given in **Table A5** (Appendix VII).

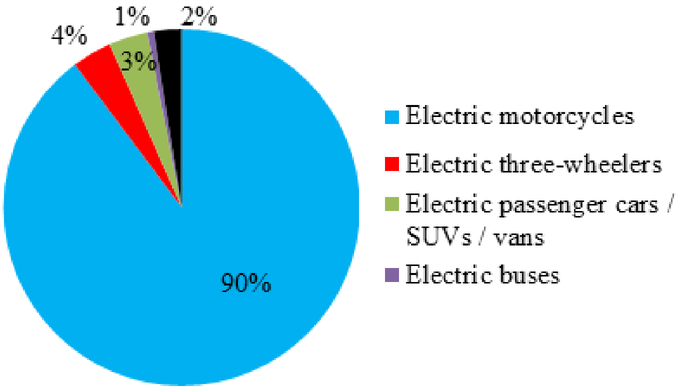

Figure 4. 5: Composition of the current EVs fleet in Kenya in 2024

The results in **Figure 4.5** reveal a pronounced dominance of electric motorcycles, which account for 8,097 out of a total of 9,019 EVs, representing approximately 90% of all registered EVs. This overwhelming share reflects the rapid adoption of electric mobility within the informal transport sector, particularly in the motorcycle taxi (usually called '*boda-boda*' in Kenya) industry, where affordability and operational flexibility are critical. Electric three-wheelers constitute 4% of the total with 324 units, likely serving both light commercial and short-range transport needs. Electric passenger cars, SUVs, and vans closely follow with 318 units (3%), indicating a modest yet emerging uptake in private and institutional electric mobility. Electric forklifts and other industrial or commercial EVs make up 2% of the total, with 227 registered units, reflecting a growing presence in non-passenger applications. Meanwhile, electric buses remain the least represented category at just 53 units, comprising only 1% of all EVs. The data highlights the prevailing orientation of Kenya's EV market toward two- and three-wheeled vehicles, largely driven by affordability, operational ease, and compatibility with existing transport models. In contrast, adoption within larger, capital-intensive segments remains limited, constrained by infrastructural gaps, high acquisition costs, and the slow pace of supportive policy implementation.

4.3 Available Charging Processes

A survey was carried out to determine the number of charging stations and their locations using a questionnaire presented in Appendix VIII. **Figure 4.6** presents the results obtained on the distribution of charging points across available charging stations in Kenya. The data used to plot this graph is tabulated in **Table A6** (Appendix IX).

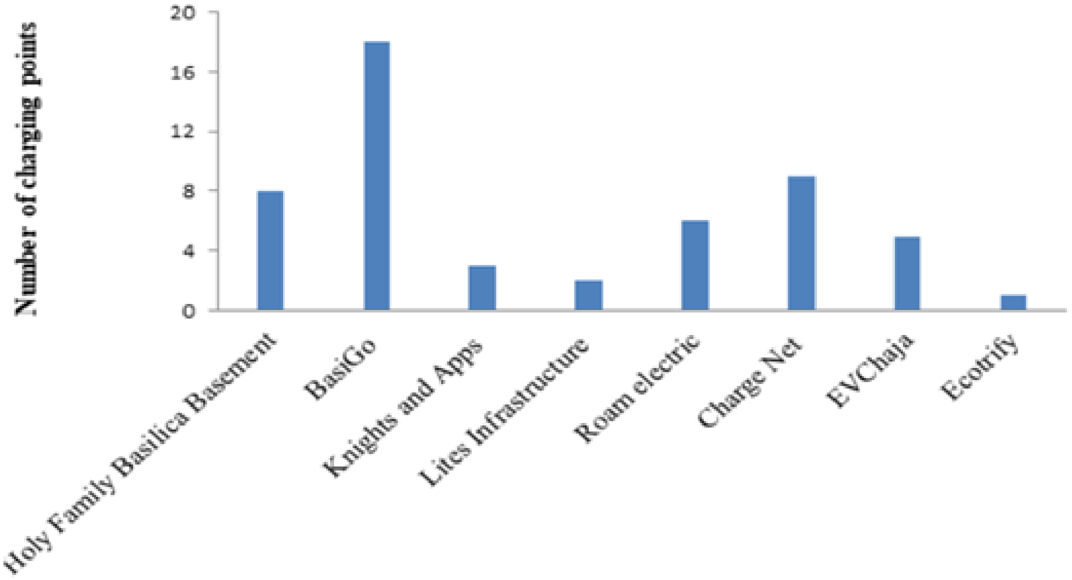

Figure 4. 6: EV public charging infrastructure in Kenya

From **Figure 4.6**, BasiGo emerges as the leading provider, operating 18 charging points across its stations in Buruburu, Embakasi, and Kikuyu. This concentration suggests a strategic focus on high-capacity charging hubs, likely aimed at supporting electric bus fleets and transit-oriented operations. The Holy Family Basilica Basement station ranks next with 8 charging points, indicating efforts to integrate EV infrastructure within central urban facilities. Charge Net, operated by Mayleen Corporation, also features prominently with 9 points, reflecting increased private sector participation in establishing accessible urban charging infrastructure. Other providers contribute modestly to the national charging landscape. Roam Electric maintains 6 charging points, while EVChaja and Knights and Apps (operating under Drive Electric) offer 5 and 3 points respectively. Lites Infrastructure Company accounts for 2 points, and Ecotrify features a single installation, possibly representing early-stage or pilot deployment. The distribution reflects a nascent but expanding sector, where a few major players dominate, while smaller actors occupy niche or experimental roles. The observed pattern underscores the need for coordinated policy support, investment incentives, and strategic infrastructure planning to ensure equitable access and nationwide coverage of EV charging facilities as Kenya advances its transition to sustainable mobility.

Table A7 (Appendix X) present wattage and charging levels for the stations presented in **Figure 4.6** above. Charging processes are predominantly concentrated at Level 2, which recorded forty six (46) installations or operational setups, indicating that this category constitutes the most accessible tier of charging infrastructure in the current Kenyan context. Level 3 registered a modest presence with 9 processes, suggesting limited but emerging development of more advanced or specialized charging solutions. Notably, Level 1 exhibited no available charging processes, highlighting either a lack of basic-level charging infrastructure or a strategic decision to bypass this tier in favour of more scalable technologies. This distribution reflects an emphasis on mid-level charging capabilities, which may balance cost, functionality, and compatibility with existing grid systems.

The spatial distribution of available charging stations reveals a pronounced concentration in Nairobi, with 8 documented stations, signifying the city's central role in early-stage EV infrastructure deployment. Other cities or towns in Kenya as Nakuru, Mombasa, Nanyuki, and Thika each registered only a single charging point, underscoring a stark regional disparity in access to charging facilities. This uneven deployment may be attributed to infrastructural, economic, or policy-driven factors that favour urban centres, particularly the capital highlighting the urgent need for a more decentralized rollout strategy to ensure equitable access to charging infrastructure across various regions as EV adoption expands nationally.

4.4 Capacity of Kenya's Sustainable Energy Resources to Meet 2063 Energy Demand

Figure 4.7 presents the results on the projected electricity demand for EVs in comparison with other major consumers, primarily the domestic and industrial sectors, from 2010 to 2063. The electricity demand for EVs was calculated using Equations (3.2), (3.3), and (3.4), while that from domestic and industrial sectors were calculated using Equations (3.6) and (3.7) and the generated data are tabulated in **Table A8** (Appendix XI) .

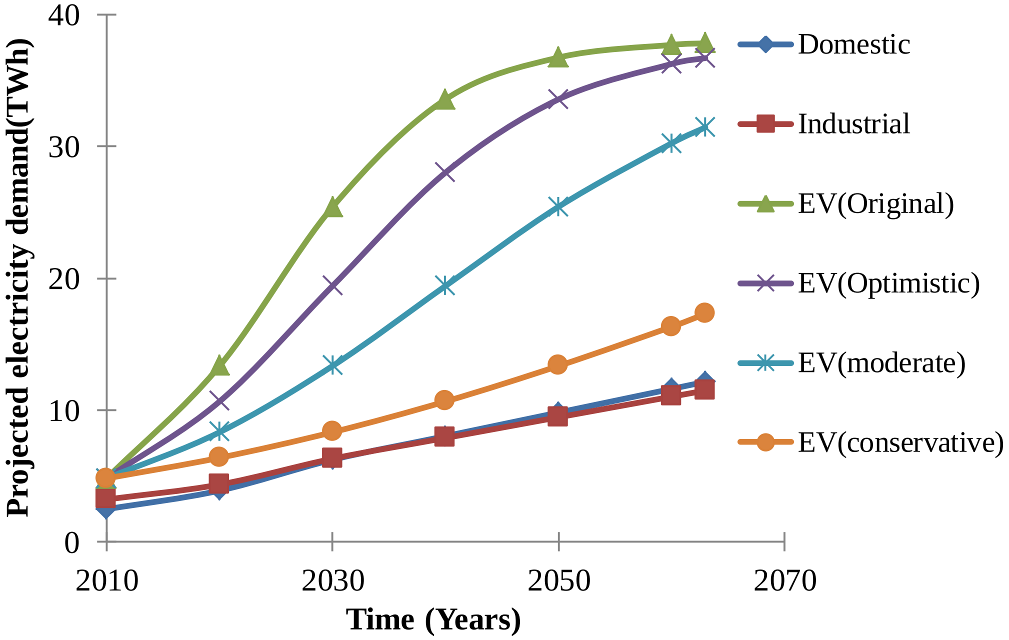

Figure 4. 7: Projected Electricity demand for EVs and Other sectors.

The number of IECVs in Kenya in 2010 was 1.42 x 10^6 vehicles (see **Figure 4.1**) and if all of them (original scenario) were to be electrified, then the electricity demand would be

4.82 TWh. Results show that domestic consumption will rise from 2.49 TWh in 2010 to 12.15 TWh by 2063, while industrial demand will grow from 3.23 TWh to 11.49 TWh in the same period. On the other hand, electricity demand from EVs under the conservative, moderate, optimistic, and original scenarios is expected to reach 17.30 TWh, 31.44 TWh, 36.70 TWh, and 37.82 TWh, respectively. Total national electricity requirements are projected to range between 40.94 TWh and 61.46 TWh by 2063.These projections confirm that EV growth will be the dominant driver of future electricity demand in Kenya, necessitating urgent planning for expanded and sustainable energy generation.

Based on Equation (3.5), the net electricity required to meet sectoral demand in 2063 significantly exceeds the raw consumption figures. After adjusting for these factors, the net electricity demand from EVs rises to 24.33 TWh under the conservative scenario, 44.23 TWh under the moderate scenario, 51.62 TWh under the optimistic scenario, and 53.19 TWh under the original scenario. In addition, the domestic and industrial sectors will require 15.38 TWh and 14.54 TWh, respectively. This brings the total net electricity requirement in 2063 to 54.25 TWh (6193 MW), 74.15 TWh (8465 MW), 81.54TWh (9308 MW) and 83.11 TWh (9488 MW) for conservative and original EV cases respectively.

Figure 4.8 presents Kenya's renewable energy generation capacity from 2013 to 2024, highlighting distinct trends across different energy sources. The data used to plot these graphs were obtained from KNBS and is presented in **Table A9** (Appendix XII).

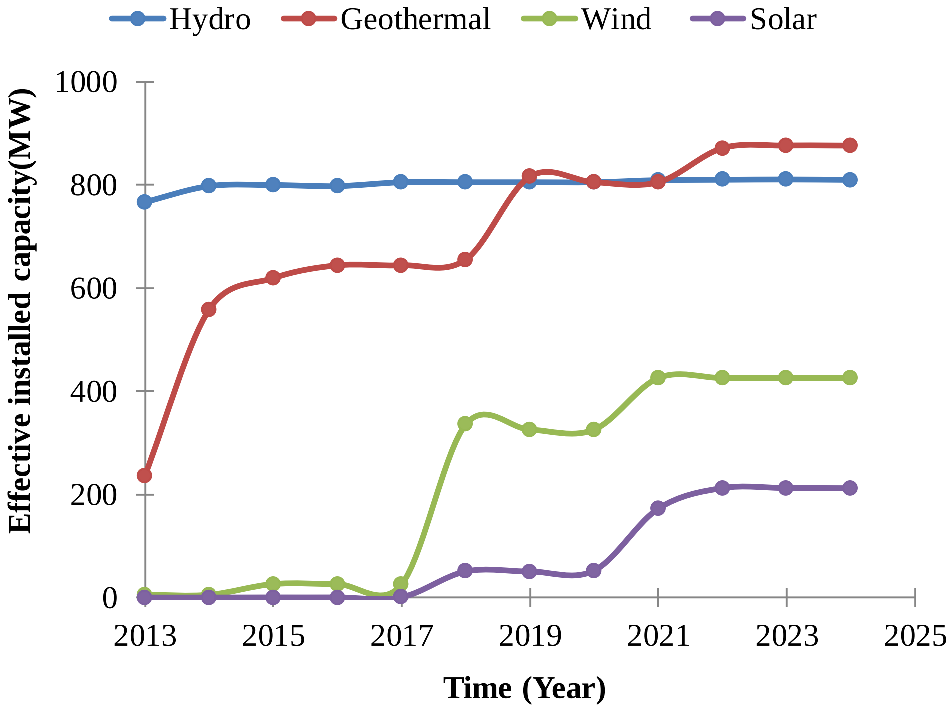

Figure 4. 8: Kenya's renewable energy generation capacity

From the results in **Figure 4.8**, between 2013 and 2024, Kenya's renewable energy capacity expanded significantly, driven primarily by geothermal, wind, and solar sources. Geothermal energy recorded the most substantial growth, rising from 236.5 MW in 2013 to 876.1 MW in 2024, surpassing hydropower, which remained relatively stable at around 800 MW throughout the period. Wind energy increased sharply from 5.3 MW in 2013 to 425.5 MW by 2021, maintaining that level thereafter. Solar energy, initially negligible, grew steadily from 0.2 MW in 2015 to 211.9 MW in 2024.

The results in **Figure 4.8** were replotted but with the independent variable (i.e. years) itemized beginning with 2015 as the first (1) year. This was done to get appropriate regression equations that could describe the growth of the main stream renewable energy sources in Kenya. The resulting graphs are plotted in **Figure 4.9**, and the resulting equations were used to estimate effective generation capacities of each source by 2063.

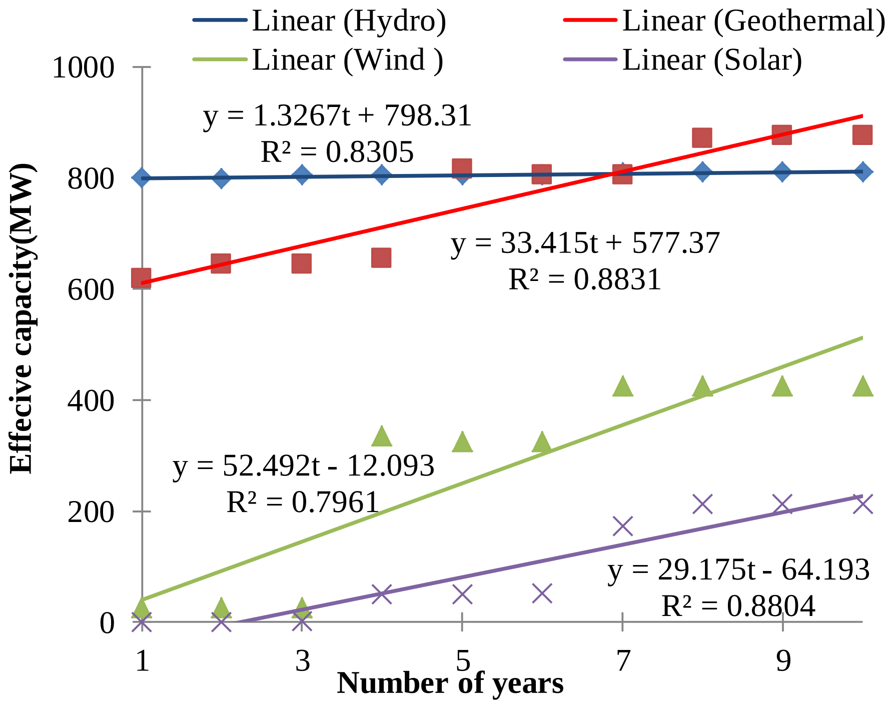

Figure 4. 9: Projected generation capacities of renewable energy in Kenya under BAU

Time (*t*) dependent regression equations under the Business-As-Usual (BAU) scenario describing the effective capacity (MW) for the different renewable energy sources were found to be linear with relatively high R^2 vales as indicated in Figure 4.9 and are given as follows:

$$P_{geothermal} = 33.415t + 577.37 \tag{4.4}$$

$$P_{hydro} = 1.3267t + 798.31 \tag{4.5}$$

$$P_{wind} = 52.492t - 12.093 \tag{4.6}$$

$$P_{solar} = 29.175t - 64.193 \tag{4.7}$$

From these equations, the projected effective capacities from the different renewable energy source were respectively 2181.3 MW, 862 MW, 2507.5 MW and1336.2 MW for geothermal, hydro, wind and solar by 2063, giving total projection of 6887 MW by 2063. Comparing with the projected total electricity demand obtained from **Figure 4.7** of 6193 MW and 9488 MW for conservative (lowest) and original (highest) adaptation scenarios respectively. This clearly shows that the projection from regression analysis will be sufficient to meet the demand for conservative and not original option. For conservative scenario, the projected generation from **Figure 4.9** surpasses that in **Figure 4.8** by 694 MW (10.1%), but is deficient by 2601 MW (37.8%) for original scenario. Therefore, if all ICEVs (original scenario) were to be replaced with EVs by 2063, then the power generation from the renewable energy sources will not be sufficient to meet all the load demand in the country.

From the results in **Figure 4.3**, the moderate scenario was projected to be the most likely adoption option for the EVs by 2063, and the corresponding projected electricity demand from **Figure 4.7** is 8465 MW. This means that the possible adoption scenario of EVs will have a deficit of 1578 MW (22.9%). Therefore, the capacity of renewable energy to exclusively power the growth of EVs by the year 2063 is not enough except in the conservative scenario. The country, therefore, must increase generation capacities for renewable energy resources with huge potential like solar energy in order to meet the projected power demand as a results of the increasing EVs adoption.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The analysis of vehicle growth dynamics in Kenya between 2010 and 2024 shows the dominance of ICEVs, which rose from about 1.4 million units in 2010 to 4,884,057 in 2024, compared to the more recent adoption of EVs, which began in 2016 and reached 9,019 units by 2024, nearly 90% of them are motorcycles. Although EVs currently represent only 0.02% of all registered vehicles, their sharp growth after 2021 reflects rising environmental awareness, supportive policies, higher fuel prices, and gradual charging infrastructure development. Projections for 2063 from regression analysis and the moderate scenario of the LGM estimate 8,196,769 and 9,246,810 EVs respectively, with a deviation of 12.8% when regression value is taken as the baseline. The current dominance of motorcycles underscores affordability and structural constraints, yet overall the evidence suggests EVs are moving from early adoption toward broader diffusion and could form a substantial share of the national fleet by mid-century. However, this growth will place significant new demands on Kenya's energy systems as transportation becomes increasingly electrified.

The available charging processes demonstrate that Kenya's EVs infrastructure remains highly uneven, with Nairobi emerging as the dominant hub while other cities and towns lag significantly behind. Charging facilities are concentrated among a few providers, with BasiGo, Holy Family Basilica, and Charge Net leading the sector, while smaller players contribute marginally. The predominance of Level 2 charging, alongside the limited presence of Level 3 and absence of Level 1 processes, suggests a strategic prioritization of mid-tier charging technologies that balance scalability and grid compatibility. However, the current urban bias and fragmented distribution highlight critical challenges for nationwide EV adoption. Incentives, targeted investments, and regionally inclusive infrastructure planning will be essential to foster equitable access, strengthen driving range confidence, and support Kenya's broader transition to sustainable mobility.

The estimated electricity demand associated with the projected EVs growth under moderate scenario (50%) is 5049 MW by 2063. When combined with expected growth in domestic and industrial electricity demand of 1756 MW and 1660 MW respectively, the total national net electricity requirement could reach 8465 MW. In response, Kenya's renewable energy effective capacity is projected to expand from 2323.2 MW in 2024 to approximately 6887 MW by 2063, largely driven by geothermal, solar, and wind power. This projection will fall short of the net required electricity by 1578 MW, but Kenya's untapped renewable potential highlights the need for accelerated investments and strategic planning to bridge the gap, ensure energy security, and support a sustainable low-carbon future in transportation and energy sectors.

5.2 Recommendations

Based on the findings of this study, several areas warrant further research to support the sustainable growth of electric vehicle adoption and energy planning in Kenya.

i. Further studies should be conducted on EV driving ranges under Kenya's real operating conditions such as climate, road terrain, and travel patterns to provide accurate range information for vehicles in the country.

ii. A continuous comparative analysis of EVs and ICEVs growth rates should be conducted to track transition patterns, forecast market saturation points, and guide phased infrastructural, policy, and investment decisions aligned with Kenya’s sustainable transport targets.

iii. Further research is recommended on the performance of different EV batteries under Kenya’s diverse environmental conditions, including high temperatures, varied topography, and long-distance travel patterns, to improve driving range and reduce charging frequency.

iv. Future research should refine long-term projections of EV growth and national electricity demand by incorporating dynamic variables such as technological developments, energy pricing, population growth, urbanization, and evolving transport behaviors.

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APPENDICES

APPENDIX I

LGM DERIVATION

The logistic model accounts for growth with a maximum limit L

$$\frac{dE}{dt} = kE\left(1 - \frac{E}{L}\right) \qquad (1)$$

Where E(t) is the quantity at time t, *k* is the growth rate, and L is the carrying capacity.

Separating the variables,

$$\frac{dE}{E\left(1 - \frac{E}{L}\right)} = kdt \qquad (2)$$

Decomposing LHS into partial into partial fractions,

$\frac{A}{E} + \frac{B}{(L-E)} = \frac{L}{E(L-E)}$ which yields A=B=1 when solved thus equation (2) becomes,

$$c + \frac{dE}{(L-E)} = kdt \qquad (3)$$

Integrating both sides ,

$$\int \frac{dE}{E} + \int \frac{dE}{(L-E)} = \int kdt \qquad (4)$$

Yielding

$\ln E - \ln(L - E) = kt + C$, which gives

$$\ln\left(\frac{E}{L-E}\right) = kt + C \qquad (5)$$

Applying exponentials on both sides of Eq.5 gives

$$\frac{E}{L-E} = De^{kt} \qquad (6)$$

where $D = e^{C}$

thus

$$E(t) = \frac{LDe^{kt}}{1+De^{kt}} \qquad (7)$$

Applying initial conditions, when *t=0*, $E = E_0$

$$\frac{E_0}{L-E_0} = D \qquad (8)$$

Substituting for D in Eq. 7 gives

$$E(t) = \frac{L}{1+(\frac{L}{L-E_0})e^{-\mathrm{kt}}} \tag{9}$$

APPENDIX II

Table 1: Energy demand from domestic and industrial sector (GWh, KNBS, 2024)

Year	Domestic	Industrial
2010	2491.1	3225.4
2011	2777.5	3458.2
2012	2948.6	3429.8
2013	3293.3	3602.5
2014	3352.5	3914
2015	3751.5	4049.2
2016	3828.8	4192.6
2017	4108.9	4259.1
2018	3966.3	4404.7
2019	4349.1	4504.9
2020	3901	4355.5
2021	4737.4	4828
2022	4956	5052.4
2023	4911.8	5408.9
2024	5143.9	5605.1

APPENDIX III

Table 2: Vehicle Fleet by Fuel Type Fleet (KNBS, 2024)

Year	ICEVs	EVs
2010	1417539	0
2011	1616745	0
2012	1789789	0
2013	2011972	0
2014	2210907	0
2015	2457588	0
2016	2703484	1
2017	2989588	200
2018	3280584	350
2019	3608110	630
2020	3954039	800
2021	4352891	1000
2022	4587420	1350
2023	4780673	3753
2024	4941892	9019

APPENDIX IV

MATLAB CODE

```
% Define the data
Year = (2010:2022)';
Vehicles = [1417539
1616745
1789789
2011972
2210907
2457588
2703484
2989788
3280934
3608110
3954839
4353891
4588770];

% Define the logistic growth function
logistic_growth = @(params, t) params(1) ./ (1 + ((params(1) - params(2)) ./ params(2)) .* exp(-params(3) * (t - 2010)));

% Initial guess for parameters [L, E0, k]
initial_guess = [5e6, 1e6, 0.1];

% Nonlinear regression to fit the model to the data
params_fit = lsqcurvefit(logistic_growth, initial_guess, Year, Vehicles);
```

```
% Extract fitted parameters
L = params_fit(1);
E0 = params_fit(2);
k = params_fit(3);

% Display the fitted parameters
disp(['Carrying Capacity (L): ', num2str(L)]);
disp(['Initial Value (E0): ', num2str(E0)]);
disp(['Growth Rate (k): ', num2str(k)]);
```

APPENDIX V

Table 3: LGM Projections

Year	Original	Optimistic	Moderate	Conservative
2010	1420000	1420000	1420000	1420000
2015	2450109	2150364	1879408	1636418
2020	3927141	3135768	2450108	1879409
2025	5712830	4355274	3135768	2150365
2030	7475168	5712830	3927131	2450109
2035	8898744	7056904	4799268	2778797
2040	9873629	8241737	5712830	3135768
2045	10468270	9183925	6620267	3519417
2050	10805702	9873629	7475274	3927131
2055	10989373	10348503	8241737	4355274
2060	11087088	10661831	8898744	4799268
2063	**11 122 187**	**10 795 415**	**9246810**	**5087062**
2065	11138441	10862801	9440660	5253753
2070	11165256	10989373	9873629	5712830
2075	11179210	11068175	10210884	6170355
2080	11186459	11116885	10468270	6620267
2085	11190222	11146859	10661831	7056904
2090	11192174	11165256	10805702	7475274
2095	11193186	11176526	10911729	7871261
2100	11193711	11183423	10989373	8241737

APPENDIX V1

Table 4: ICEVS Per Category Since 2010 to 2024 (KNBS, 2024)

Year	Motorcycles	Three wheels	Saloons	Pick-ups and vans	Buses	Minibuses /matatus	Station wagons
2010	117266	1521	16165	6975	1264	3600	37553
2011	140215	2140	11026	7442	1662	451	31119
2012	93970	1845	12985	7945	1638	78	39862
2013	125058	3103	16343	9819	2062	235	48662
2014	111124	4327	15902	12568	2210	213	53542
2015	134645	4775	14369	13878	2342	581	54120
2016	119724	3815	12490	12722	1765	519	46123
2017	186434	5167	11376	9866	1072	459	55322
2018	188994	6259	10504	11220	1065	812	64179
2019	210103	7322	9971	10189	1339	1932	72512
2020	246705	5896	7754	6065	900	1084	57962
2021	285203	6350	8170	5986	893	882	64350
2022	131513	4001	6350	10901	2173	907	55004
2023	70,691	5,760	6,378	12,957	3,122	1,579	61,711
2024	68,804	4,064	5,367	5,879	1,452	1,441	64,204

APPENDIX VII

Table 5: EV Numbers Per Category

EV category	**Registered units**
Electric motorcycles	8,097
Electric three-wheelers	324
Electric passenger cars / SUVs / vans	318
Electric buses	53
Electric forklifts and other commercial/industrial vehicles	227

APPENDIX VIII

QUESTIONAIRE

Dear Electric Vehicle Charging Station Owner,

I am conducting a research study as part of my Master of Science program at the University of Eldoret. The study seeks to gain insights into the operations, challenges, and future prospects of electric vehicle (EV) charging infrastructure in Kenya.

Your participation in this interview is highly valuable, as it will provide practical perspectives on the current state of EV charging stations, user experiences, and opportunities for expansion. The information you share will contribute to a better understanding of the role of charging infrastructure in supporting the adoption of electric mobility in Kenya.

All responses will be treated with confidentiality and used solely for academic purposes. I sincerely appreciate your time and contribution to this research.

Thank you.

Name: Rogers Kipsang
Institution: University of Eldoret
Course: Master of Science in Physics
Contact Information:
Email: kipsangroger74@gmail.com
Phone: +254794066764 / +254705055618

1. **Background Information**
    a. Name of the charging station owner: ….…………………………………………
    b. Name of the charging station/business: ……….…………………………………
    c. Contact information (email/phone):……………………………………………
2. **Charging Station Details**
    a. Location of the charging station
        Address: ……………………………………………………………………….
        City: …….……………………………………………………………...…
        County: ...………………………………………………………………….
    b. Number of charging points/stations available:………………..…………………
    c. Types of charging stations (level 1, level 2, DC fast charging): ………………….
    d. Charging power and voltage specifications:……………………………………
3. **Business Operations**

a. When did the charging station open for operation?.......................................
b. How many days of the week do you operate?……………………………………
c. How many of each of the following vehicles do you charge daily?

Vehicle type	Motorcycles	Three-wheelers	Saloons	Vans	Buses	Lorries	Others (Specify)
No. of daily charges							

d. How many electric vehicle owners use your charging station; daily?...................

4. Charging Services

a. What is your charger rating?…………………………………………………….
b. What is the average state of charge in percentage of the vehicle batteries brought to you for charging?................................………………………………
b. To what average battery capacity do you charge their vehicles.............................
c. Are there any peak hours where your charging service is highly on demand during the day? If any then specify:…………………………………………...

5. Technical Support

a. How do you handle maintenance and repairs of the charging stations?
…………………………………………………………………………………
b. What steps do you take to ensure the charging infrastructure is always operational?
…………………………………………………………………………………

6. Partnerships and Collaborations

a. Are you associated with any electric vehicle manufacturers or organizations?
………………...
b. Do you collaborate with other businesses or organizations to promote electric vehicles?
…………………………………………………………………………………

7. User Experience and Feedback

a. What efforts do you make to enhance the user experience at your charging station?
…………………………………………………………………………………
b. How do you gather and act on customer feedback?

……………………………………………………………………………………
……………………………………………………………………………………

8. **Future Expansion**
    a. Do you have plans to expand the charging station network in the future?
    ……………………………………………………………………………………
    b. Are you considering offering additional charging technologies (e.g., wireless charging, battery swaps etc) in the future? …………………………………

9. **Environmental Impact**
    a. How do you ensure that your charging station operates in an environmentally friendly manner?
    ……………………………………………………………………………………
    b. Do you have any plans to integrate renewable energy sources to power your charging stations?
    ……………………………………………………………………………………

10. **Challenges and Solutions**
    a. What challenges have you faced in operating an EV charging station?
    ……………………………………………………………………………………
    b. How do you overcome those challenges and ensure smooth operations?
    ……………………………………………………………………………………

11. **Electric Vehicle Adoption**
    a. How do you see the growth of electric vehicles in your region/country in the coming years basing on the number of EVs you charge daily?
    ……………………………………………………………………………………
    b. What role do you think charging stations play in accelerating EV adoption?
    ……………………………………………………………………………………

12. **Advice for Potential EV Charging Station Owners**
    a. What advice would you give to someone considering starting their own EV charging station business?
    ……………………………………………………………………………………

APPENDIX IX

Table 6: EV Charging Stations Summary

Charging station	**Number of charging points**
Holy Family Basilica Basement	8
BasiGo (Buruburu, Embakasi, Kikuyu)	18
Knights and Apps (Drive Electric)	3
Lites Infrastructure Company Charging Station	2
Roam electric	6
Charge Net Charging Station (Mayleen Corp.)	9
EVChaja	5
Ecotrify	1
Nopea (Ceased Operations)	12

APPENDIX X

Table 7: Available charging infrastructure

Charging Station	Location	Description	Total Charge Points	Level of Charging
Holy Family Basilica Basement	Central Business District, Nairobi	7.4 kW, single-phase AC power charge point Mode 3 charging with type 2 charger One charger per floor with two charging points each Primarily for public charging Provision for additional chargers	8	2
BasiGo	Buruburu, Embakasi, Kikuyu(Rungiri)	60 kW	● 12 ● 6	● 2 ● 3
Knights and Apps (Drive Electric)	Great Jubilee Center, Karen	-7.4 kW	3	2
Lites Infrastructure Company Charging Station	CBD (Haile Selassie Avenue)	- 7.2 kW (32 A), single-phase AC power charger Mode 3 charging with two type 2 sockets - One charge point- Primarily for public charging	2	2
Roam electric	Thika Bus Station, Green Park Terminus, Marble Arch	- 180 kW (200 A) DC output power charger Mode 4 charging with CCS2 charger Primarily for public charging	6	3
Charge Net Charging Station (Mayleen Corporation)	ABC Mall Westlands, Ramuk Towers Westlands, Be Energy Racecourse,	- 6.6 kW, single-phase AC power charge point Mode 3 charging with type 2 and type 1 chargers One charging point at each station Primarily for public	9	2

	Hass Petrol Station Kasarani, The Arch Place Nyangumi Rd., Delta Hotel University Way, Gate 45 Karatasi, and Parklands West	charging Billing: KES 4/min (type 1), KES 7/min (type 2 Payment: Mobile money (M-Pesa)		
EVChaja	Nairobi(Two Rivers mall,Waterfront-Karen),Nanyuki, Nakuru, Mombasa(City Mall Nyali)	22.0kW	5	2
Ecotrify	Nairobi(Mpuuga gardens,Hurlingham court)	7kW	1	2

APPENDIX XI

Table 8: Electricity Demand 2063 projections (TWh)

Year	Domestic	Industrial	Original	Optimistic	Moderate	Conservative
2010	2.49	3.23	4.83	4.83	4.83	4.83
2020	3.9	4.36	13.35	10.66	8.33	6.39
2030	6.24	6.32	25.41	19.42	13.35	8.33
2040	8.03	7.89	33.57	28.02	19.42	10.66
2050	9.82	9.46	36.74	33.57	25.42	13.35
2060	11.61	11.02	37.7	36.25	30.23	16.32
2063	12.15	11.49	37.82	36.70	31.44	17.30

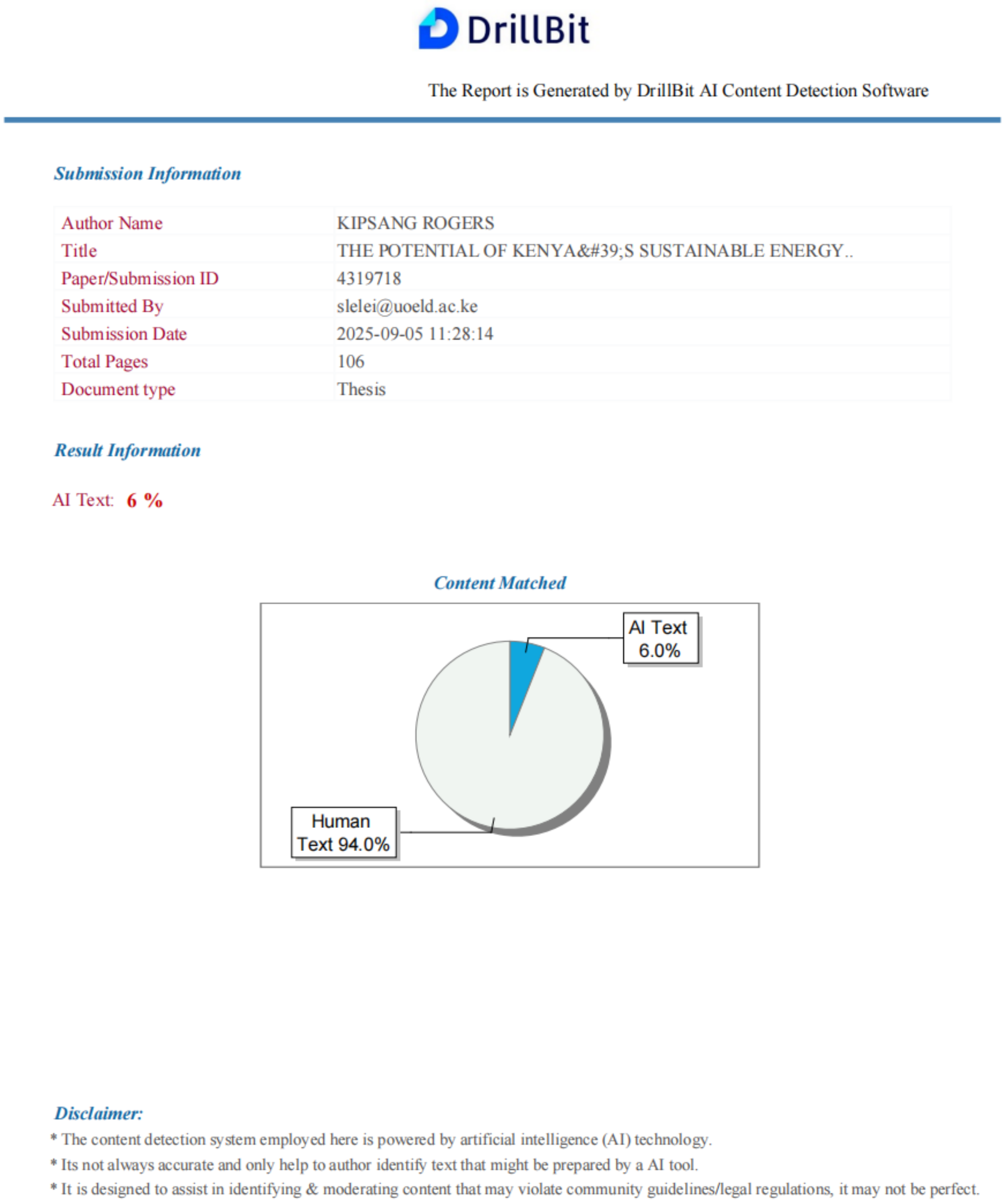
APPENDIX XII

Table 9: Effective capacities from 2013-2024 (KNBS, 2024)

Year	Hydro	Geothermal	Wind	Solar
2013	766.6	236.5	5.3	0
2014	797.5	558	5.3	0
2015	799.5	619	26.1	0.2
2016	797.5	644	26	0.2
2017	805	644	25.5	0.6
2018	805	655	335.5	50.6
2019	805	816	325.5	50.4
2020	805	805.1	325.5	52.2
2021	809.1	805.1	425.5	172.2
2022	809.9	871.1	425.5	212.2
2023	810.4	876.1	425.5	212.2
2024	809.7	876.1	425.5	211.9

APPENDIX XIII

REPORT ON AI CONTENT



DrillBit

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Submission Information

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APPENDIX XIV

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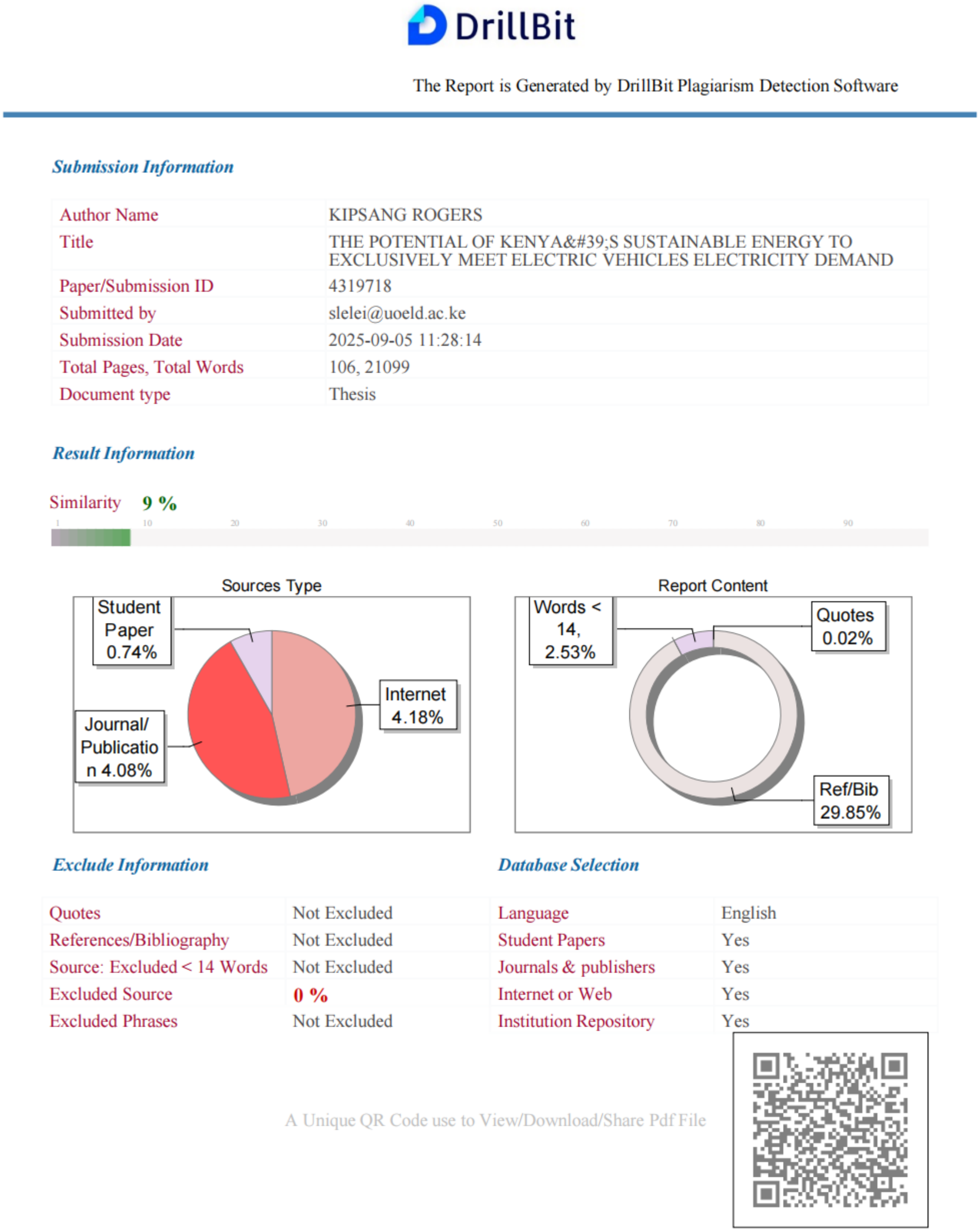

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