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THE LONG-TERM FORECAST OF GHANA'S ENERGY SUPPLY AND DEMAND: LOW EMISSION ANALYSIS PLATFORM (LEAP) APPLICATION MODEL

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF REQUIREMENT FOR THE AWARD OF MPHIL IN CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT DEGREE.

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DECLARATION

I declare that this work represents my original research under the supervision of Prof. Nana Ama Browne Klutse and Dr. Yaw Agyeman Boafo and has not been submitted for academic honour at the University of Ghana or any other educational institution. I have duly cited all sources used in this study.

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CERTIFICATION

I hereby certify that this thesis was supervised under procedures laid down by the University of Ghana.

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DEDICATION

I humbly dedicate this thesis to myself (**Seyram Dunyo**) for my unwavering determination and perseverance throughout this journey. I also extend this dedication to my entire family and loved ones, whose steadfast support, encouragement, and love have been a source of endless motivation. This accomplishment is as much theirs as it is mine. Thank you for being my rock and my strength.

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ABSTRACT

Ghana, a rapidly evolving nation in West Africa, is confronted with the task of meeting its escalating energy needs while making the shift towards a sustainable, low-carbon energy future. This research endeavours to create a comprehensive long-term projection of Ghana's energy demand and supply using the Low Emission Analysis Platform (LEAP), with a specific focus on identifying pathways for reducing greenhouse gas (GHG) emissions. The study follows a quantitative research approach, gathering historical data on energy supply and demand as well as socio-economic indicators from diverse sources. Utilising the LEAP, the data is analysed to forecast energy demand and supply under two scenarios: business-as-usual (BAU) and mitigation and policy scenarios. The study's findings suggest that Ghana's energy demand is projected to experience significant growth in the coming decades, driven by population expansion, economic progress, and urbanisation. It is expected that household energy demand will be the largest, comprising 63% of the total demand, followed by transport (21.5%), industry (12.3%), and commerce (2.2%) under the mitigation and policy scenario. Similarly, in the baseline scenario, household demand is anticipated to constitute 49.3% of the total, followed by transport (28.2%), industry (19.4%), and commerce (3.1%). In the base year, energy demand was distributed as follows: households (44.1%), industry (16.1%), transport (34.4%), and commerce (5.4%). However, there is a projected insufficient energy supply in the country due to the increasing demand. This would result in an energy gap, as it is estimated that the four energy sectors analysed in this study will consume about 45% of the total energy supply by 2030, decreasing to nearly 40% in 2040 and 35% in 2050. The study emphasises that this gap could be closed by increasing the penetration of renewable energy from sources like solar and wind power to 30% by 2030 and 50% by 2050, reducing Ghana's reliance on fossil fuels. Additionally, the analysis using the LEAP

shows that Ghana can significantly reduce its greenhouse gas emissions by implementing low-carbon strategies such as promoting renewable energy, adopting energy efficiency measures, and enhancing energy infrastructure. The study's findings have led to several policy recommendations aimed at shaping Ghana's energy future. These recommendations include enhancing renewable energy policies, implementing demand-side management strategies, investing in energy infrastructure, promoting energy efficiency standards, and establishing a carbon pricing mechanism. The insights provided by this study are valuable for policymakers, energy stakeholders, and researchers in Ghana and beyond. The application of the LEAP model has demonstrated its effectiveness in long-term energy planning and policy analysis, particularly in the context of developing countries with limited data availability. This study contributes to the expanding knowledge base on sustainable energy development and climate change mitigation in Africa.

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CHAPTER 1 (ONE)

INTRODUCTION

1.0 Background

Climate change remains one of the most pressing global challenges, with profound impacts on weather patterns, ecosystems, and human livelihoods. Its effects in Ghana have become increasingly pervasive, evident in erratic rainfall, rising temperatures, droughts, and extreme flood events (Awuni et al., 2023). These climate disruptions adversely affect not only agricultural productivity and water availability, but also food security and economic stability, especially in rural areas where the majority rely on rain-fed agriculture (Adjei-Mensah & Kusimi, 2020; Bawayelaazaa, 2016).

The centrality of the energy sector in the climate change discourse is clear: globally and in Ghana, energy production and use are the largest sources of greenhouse gas (GHG) emissions (Khan et al., 2014; Ghana National Greenhouse Gas Emission Report, 2019). Ghana's energy sector is experiencing increasing demand, driven by population growth, rapid urbanisation, and economic development (Nyasapoh et al., 2022a; Quartey, 2023a). However, this growth has come with an increased reliance on thermal generation from fossil fuels, resulting in elevated carbon emissions and import dependence, which compromise environmental sustainability and energy security (Atuahene, 2022; Atuahene & Sheng, 2023). With dominant greenhouse gases in the atmosphere being carbon dioxide (70.1%), nitrous oxide (14.3%) and methane (13.7%), most of these GHG emissions in Ghana come from the energy sector (45.7%) and agriculture, forestry, and other land use (44.6%), making energy consumption and production a major focus for reducing carbon emissions (Ghana National Greenhouse Gas Emission Report, 2019).

Despite recent policy and infrastructural efforts, Ghana's energy mix remains dominated by conventional sources: 61% thermal (mainly natural gas), 38% hydro, and less than 1% solar (Atuahene & Sheng, 2023). Renewable energy's potential, especially solar and wind, remains underexploited, and the country faces significant challenges in meeting both demand growth and decarbonization targets (Takase et al., 2022; Kumi & Mahama, 2023). The government's goal of increasing renewables' share to 10% by 2030 underscores the urgency for long-term, data-driven planning and transition (Energy Commission, 2019).

Critically, Ghana's energy system is constrained by recurrent supply gaps, reliability issues, and persistent dependence on imported fossil fuels (Agyekum, 2020; Ankrah & Lin, 2020). Rural-urban disparities in access and affordability further exacerbate energy poverty, while heavy reliance on traditional biomass in many households continues to drive health and environmental problems (Ghana Statistical Services, 2022; Yiran et al., 2020).

1.0 Problem Statement

Ghana's persistent inability to reliably forecast energy supply and demand undermines both developmental and climate policy objectives (Akom et al., 2020). The absence of an integrated forecasting framework impedes stakeholders from formulating informed policies and investment decisions, resulting in periodic shortages, underutilization of renewable resources, and stalled progress toward GHG emission reduction.

Although government strategies and some academic studies provide energy sector insights, there is a paucity of comprehensive, integrated, scenario-based long-term forecasting tools tailored for the Ghanaian context (Akom et al., 2020; Abledu, 2013; MacLean et al., 2016). Existing analyses often focus either on a single sector (such as electricity) or lack granularity in accounting for policy, technology, and economic drivers, as well as the implications of low-carbon transition scenarios on emissions and energy security (Nyasapoh et al., 2022b; Mukoro et al., 2021).

These gaps are further complicated by challenges in data availability, calibration, and validation of energy models for developing countries like Ghana (Dranka et al., 2021; Gebremeskel et al., 2023). The limitations of previous approaches, including outdated or incomplete data, insufficient stakeholder integration, and limited scenario analysis, hinder Ghana's ability to design robust, future-proof energy policies.

In this context, the Low Emission Analysis Platform (LEAP) model emerges as a globally recognised, flexible tool for integrated long-term energy and environmental planning, yet its application to Ghana remains nascent and underutilised (Amo-Aidoo et al., 2022; Huang et al., 2010). Therefore, this study explicitly addresses these shortcomings by applying the LEAP platform, a model that incorporates both quantitative and scenario-based qualitative inputs to generate robust long-term forecasts and to test the implications of various policy choices. Importantly, the research aims to link the gap in forecasting capacity to the broader expected benefits of improved planning: enhanced supply reliability, affordability, system resilience, and the identification of realistic pathways for GHG mitigation (Lund et al., 2015; Sorrell, 2015).

1.1 Research Questions

The study is guided by the following questions:

1. What are the current patterns of energy supply and demand in Ghana, and how have they evolved over time?

2. What are the key drivers of energy demand and supply in Ghana, and how are they expected to change in the long term?

3. How can the Low Emission Analysis Platform (LEAP) model be effectively adopted in the Ghanaian context for long-term energy forecasting with a low-emission focus?

1.2 Aims and Objectives

The main goal is to employ a robust, scenario-based methodology to fill Ghana's energy planning gaps and inform policymaking for a sustainable, low-carbon future. Specifically, this study aims to:

1. Model and forecast Ghana's energy supply and demand up to 2050, with a particular emphasis on low emissions.
2. Assess and analyse the different sources of energy and their effects on carbon dioxide (CO_2) emissions.
3. Evaluate the implications of different low-emission energy scenarios for energy security, specifically examining dimensions of reliability, affordability, and system resilience in Ghana.

1.3 Significance of the study

This study is a crucial analysis aimed at gaining a deeper understanding of the possible directions of energy demand and their impact on policy-making and sustainable development in Ghana. It will be informed by the Ghana Shared Growth and Development Agenda and the Coordinated Programme of Economic and Social Development Policies, which serve as the foundation for sustainable development in the country. The study will also draw on previous research and empirical studies related to energy supply and demand forecasting in Ghana, providing a comprehensive review of existing literature, theoretical frameworks, empirical studies, and research gaps related to energy supply and demand forecasting.

The study's findings will be of interest to policymakers, energy planners, researchers, and other stakeholders in Ghana's energy sector and provide them with more accurate and reliable energy forecasts to develop sustainable energy policies and strategies for the country. This will help to ensure a reliable and affordable energy supply, which is critical for the country's economic growth and development (Amo-Aidoo et al., 2022; Abban & Awopone, 2021). The study will assess the effects of various electricity generation scenarios on the environment and the energy sector. This analysis will aid in identifying the most sustainable energy policies and strategies for minimising environmental impact and advancing the use of renewable energy sources (Amo-Aidoo, A., et al., 2022; Huang, et al., 2021). Additionally, it will help in pinpointing the primary drivers of energy demand and electricity generation in Ghana, facilitating the development of strategies to address the limitations of the LEAP model and promote sustainable economic growth and development (Emodi, 2016; Abledu, 2013). The study's recommendations will help to develop sustainable energy policies and strategies that can ensure a reliable and affordable energy supply while minimising the impact on the environment (Amo-Aidooet al., 2022; Abban & Awopone, 2021).

1.4 Assumptions and Limitations

1.4.1 Assumptions

The study assumes that energy demand and supply are interconnected and that understanding their relationship is crucial for forecasting and planning. This assumption is central to the study's focus on energy supply and demand forecasting using the LEAP model. Also, the study assumes that addressing climate change is a priority for Ghana's energy sector and that sustainable development is essential for achieving this goal. This is reflected in the study's focus on low-emission energy systems. The study relies on the LEAP model for energy analysis hence, the assumption that the model's framework and assumptions are valid and applicable to Ghana's energy sector. The study assumes a nexus between population growth, economic growth, energy consumption and greenhouse gas emissions, as it aims to provide a comprehensive long-term energy planning tool that can help policymakers and stakeholders make informed decisions. Additionally, the study assumes that technological innovation and energy transition are essential for achieving low-emission and sustainable energy systems in Ghana.

1.4.2 Limitations

The study provides valuable insights into Ghana's energy supply and demand forecasting using the LEAP model which can inform policymakers and stakeholders in their efforts to develop a sustainable and low-emission energy system. However, some limitations may affect the study's ability to provide a complete economic analysis of Ghana's energy system.

The study primarily focuses on the energy sector, which may not provide a comprehensive analysis of the broader implications of energy policies on other sectors, such as agriculture, forestry, or land-use change. LEAP is best suited for integrated analyses and not for life-cycle analyses. This means that the study may not consider the entire life cycle of energy systems, from extraction to end-use, which could provide a more holistic understanding of the environmental and social impacts of energy policies.

LEAP does not automatically calculate the implications of non-climate Sustainable Development Goals (SDGs) of its least-cost energy system to meet prescribed climate or emissions constraints. This may limit the study's ability to assess the overall sustainability of Ghana's energy system. The study may have to make simplifications and exclusions in the analysis, such as turning off some complexities in LEAP by setting certain parameters to null values or limiting the representation of certain activities, such as coordinated and flexible load management in the electricity sector.

The quality of the data used in the study may affect the accuracy and reliability of the results. Ensuring the availability and accuracy of relevant data, especially for future scenarios, can be challenging and may lead to uncertainties in the analysis. LEAP has some inherent limitations, such as not estimating the impact of energy policies on employment or economic growth, nor automatically generating optimum or market-equilibrium scenarios.

Despite these limitations, this study provides valuable insights into Ghana's energy supply and demand forecasting using the LEAP model, which can inform policymakers and stakeholders in their efforts to develop a sustainable and low-emission energy system. It is therefore imperative that future studies in this field consider conducting integrated analyses that cover a wider range of sectors beyond just the energy sector. Additionally, utilizing a combination of modelling tools, including but not limited to LEAP, for a more comprehensive understanding of the implications of energy policies on both climate and non-climate Sustainable Development Goals (SDGs). Moreover, placing emphasis on obtaining high-quality and accurate data for future scenarios, as well as exploring the incorporation of parameters that LEAP currently excludes, such as the impact of energy policies on employment and economic growth, would further enhance the depth and reliability of the analysis.

1.5 Structure of the Study

The study consists of six main chapters.

Chapter one provides general background information on energy supply and demand in Ghana and looks at Ghana with a broader lens. It outlines the research objectives and questions and discusses the importance and relevance of the research. The chapter delves into the historical context of energy production in Ghana, highlighting key milestones and challenges faced by the country. It also examines current trends in energy consumption and explores potential future scenarios. By setting the stage for the rest of the research, this chapter aims to provide a comprehensive understanding of the energy landscape in Ghana and the factors driving its development. Overall, it serves as a crucial foundation for the subsequent analysis and recommendations presented in the preceding chapters.

Chapter two presents the Literature Review, which encompasses the conceptual framework, establishing the theoretical foundation for the study, and the empirical literature. It draws from existing studies and case examples to contextualise the research. It also looks at some critical topics that are relevant to this study. These topics include the role of the Low Emission Analysis Platform (LEAP) in Ghana's energy sector, energy policies in Ghana, demographic trends in Ghana and greenhouse emissions in Ghana. By examining these key themes, the Literature Review sets the stage for the research to follow, providing a comprehensive overview of the current state of knowledge in the field. Through this analysis, the study aims to build upon existing research and contribute new insights to the body of knowledge.

Chapter three provides details on the Research Design and Methods. It outlines the research design, emphasising the choice of a case study. This chapter also offers a clear understanding of the data collection process, including the methods employed. Additionally, it describes the paramount tool (the Low Emission Analysis Platform, LEAP) of the study as well as gives a detailed and comprehensive background to the Application and outlines some steps in using the application.

Furthermore, chapter delves into the specific variables that will be measured and analysed throughout the study. The chapter also discusses the potential limitations of the research design and methods, providing a transparent view of the potential challenges that may arise. In all, this chapter sets the stage for the rest of the study, providing a solid framework for data collection and analysis.

Chapters four and five present the data collected, giving an overview of Ghana’s energy demand and supply and providing a comprehensive look at Ghana's current energy landscape, highlighting both the challenges and opportunities that exist within the sector. They analyse and discuss the results obtained. They align with the research objectives, forecasting Ghana’s future energy and the impact on carbon dioxide emissions.

Chapter six of the research provides a concise summary of key findings, highlighting the research questions and objectives. It offers recommendations for improving Ghana's energy forecast, discusses policy implications, and links the research to potential actions. The chapter also considers future research areas, allowing for further exploration. By linking the conclusions to the initial research questions, the chapter highlights the study's relevance and importance. The recommendations and policy implications set the groundwork for potential policy actions to address Ghana's energy forecast challenges. The discussion on future research areas also opens opportunities for further investigation and development.

CHAPTER 2 (TWO)

LITERATURE REVIEW, THEORETICAL AND CONCEPTUAL FRAMEWORK

2.0 Introduction

The nexus between climate change, energy demand, and sustainable development has led to a proliferation of studies in energy modelling and forecasting, especially within developing country contexts such as Ghana. However, significant knowledge and methodological gaps persist, particularly regarding the integration of comprehensive scenario modelling, policy relevance, and application of advanced decision-support tools. This chapter critically reviews and synthesises major scholarly works and policy frameworks in the field, extending beyond mere description to focus on comparative analysis, debates, and gaps.

2.1 Concepts and Definitions

The main concepts that will be highlighted in this study are “climate change”, “climate security”, “energy and energy security”, “energy demand and supply”, “scenarios” and “greenhouse gases and emissions”.

2.1.1 Climate Change

Many bodies, including the United Nations (UN), have shed light and offered different perspectives on the concept of climate change. The United Nations (UN) defines climate change as the long-term alterations in temperatures and weather patterns. The organisation emphasises that these changes can occur naturally, as a result of fluctuations in the sun’s activity or major volcanic eruptions. However, since the 1800s, human activities, particularly the burning of fossil fuels such as coal, oil, and gas, have become the primary driver of climate change. This definition not only encompasses changes in temperature and weather patterns but also the detrimental effects on ecosystems and biodiversity, and emphasises the anthropogenic nature of climate change by pointing out some human activities.

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as the shift in climate directly or indirectly caused by human activities that modify the composition of the global atmosphere. These changes are in addition to the natural variability observed over comparable periods. Likewise, in the UNDP climate dictionary, climate change is described as the long-term alterations in the Earth's climate that lead to the warming of the atmosphere, ocean, and land. Weiskopf et al. (2020) echoed this definition, emphasising that climate change disrupts the balance of ecosystems that sustain life and biodiversity, ultimately impacting human health. Therefore, it is imperative to recognise climate change as a significant threat.

The National Aeronautics and Space Administration (NASA) looked at climate change from the perspective of space, using satellite data to monitor changes in Earth's atmosphere and surface temperatures. They found that there has been a significant rise in greenhouse gases in recent decades, resulting in higher sea levels and more frequent extreme weather events. Consequently, this phenomenon is defined as the long-term alteration in the typical weather patterns that characterise Earth's local, regional, and global climates. Furthermore, these changes have a wide array of observable effects that align with this definition.

The Intergovernmental Panel on Climate Change (IPCC) in 2007 described climate change in their Fourth Assessment Report (AR4) as “the change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". Climate change is defined as any alteration in the Earth's climate over time, stemming from natural variability or human activities.

2.1.2 Greenhouse Gases and Emissions

The UNFCCC defines "Greenhouse gases" as the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation. These gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). Some of these gases arise from human activities, while others occur naturally. According to the UNDP climate dictionary, greenhouse gases are gases that trap heat from the sun in our planet's atmosphere, helping to keep it warm. The document highlights that since the beginning of the industrial era, human activities have caused the release of significant amounts of greenhouse gases, leading to global warming and climate change. Studies by Gadani & Vyas (2011) and Liu et al. (2019) acknowledged these definitions by saying that greenhouse gases are the major causes of the warming of the atmosphere.

Natural greenhouse gases like water vapour, carbon dioxide, methane, ozone, and nitrous oxide have significant roles in regulating the Earth's temperature (Stojanović-Blab et al., 2022). Additionally, human activities have led to the release of greenhouse gases like CO_2, CH_4, and N_2O, which further exacerbate global warming (Liu et al., 2019). Acknowledging the degree to which these greenhouse gases have affected the world's climate, efforts are being made to mitigate greenhouse gas emissions globally to combat climate change. These gases are considered major contributors to global warming and climate change (Oliveira et al., 2017). Methane, in particular, is highlighted as the second-largest contributor to global warming, accounting for 16% of greenhouse gases (Soza & Ayres, 2018).

Similarly, the UNFCCC defines emissions as the release of greenhouse gases and/or their precursors into the atmosphere within a specified area and time frame. These emissions exist in various forms: long-lived greenhouse gases (mostly CO_2), short-lived chemically active gases (such as NOx, CO, and VOCs), and short-lived aerosols and aerosol precursors, all of which arise from different industries (Berntsen & Fuglestvedt, 2008). For example, a coal-fired power plant releasing carbon dioxide and methane into the atmosphere is considered an emission under the UNFCCC guidelines. Additionally, emissions can also come from activities such as transportation, agriculture, and industrial processes. These emissions contribute to the warming of the Earth's atmosphere and are a major factor in climate change.

One of the most concerning aspects of greenhouse gas emissions is their long-lasting impact on the environment. Once released into the atmosphere, these gases can linger for decades or even centuries, trapping heat and causing temperatures to rise (Gahlawat and Lakra, 2020). This leads to a cascade of negative effects, including melting ice caps, rising sea levels, and more frequent and severe natural disasters.

2.1.3 Energy and Energy Security

Definitions of energy and energy security have evolved from narrow supply-based notions to multidimensional constructs emphasising availability, affordability, accessibility, and acceptability (Strojny et al., 2023; Jones & Dodds, 2017). Some scholars argue that traditional approaches fail to adequately address issues of equity, gender, or socio-political disruptions (Sovacool et al., 2011). The consensus, however, is that energy security is foundational to economic and human development in Ghana, and must be approached via diversified energy portfolios, robust infrastructure, and climate-aware planning (Dahlan et al., 2022).

Energy, as defined by the U.S. Energy Information Administration (EIA), is the ability to do work and can exist in different forms such as potential, kinetic, thermal, electrical, chemical, nuclear, and others. Additionally, energy can be present as heat and work during the transfer from one body to another. This definition underscores the importance of energy in our daily lives and the various ways it can manifest itself. Whether it's the electricity that powers our homes, the fuel that runs our cars, or the food that fuels our bodies, energy is essential for sustaining life and enabling progress. It is therefore imperative to understand issues regarding energy security and sustainability to ensure a reliable and stable source of energy for future generations.

Strojny et al. (2023) provided a conceptual overview of energy security and noted that there are different perceptions of the subject. They stated that the concept of energy security is founded on three key criteria: ensuring an adequate supply of energy resources, making sure that sourcing energy is cost-effective (costs less than the perceived value it provides), and ensuring that the energy supply system is resilient against external interference. Therefore, the authors argue that energy security is a broad concept that holds significant social, economic, and political implications, particularly as energy consumption rises, regardless of its form, in both developed and developing communities. Strojny et al. (2023) stressed the importance of diversifying energy sources to ensure stability in the face of potential disruptions. They argued that a mix of traditional and renewable energy sources would provide a more resilient and sustainable energy security framework. Additionally, they highlighted the need for international cooperation and robust energy policies to address global energy challenges and ensure a secure energy future for all.

In their recent study, Dahlan et al. (2022) provided a comprehensive description of energy security from the supply perspective, conceptualising it as a multifaceted entity characterised by diverse dimensions and components quantified through metrics. Energy security, as highlighted in the study, pertains to the guarantee of sustained energy availability in different forms, adequate quantities, and at equitable prices. This concept is crucial for mitigating vulnerability to disruptions in energy supplies and meeting the growing demand for energy over time.

Energy security, as defined by the UNDP, entails the uninterrupted availability of energy in diverse forms, in ample quantities, and at affordable prices. It also encompasses reduced susceptibility to interruptions in imported supplies and the presence of both local and imported resources to satisfy increasing energy needs.

Jones & Dodds (2017) also looked at energy security comprehensively by highlighting that energy security is based on four pillars known as the four "As": availability, affordability, accessibility, and acceptability. Accessibility refers to the guarantee of energy access for all individuals, primarily by establishing a dependable infrastructure that ensures a consistent energy supply. In practice, this concept is commonly understood as maintaining affordable energy prices and reducing fuel poverty. On the other hand, acceptability focuses on addressing the adverse effects of energy production, such as pollution and environmental harm, and aims to minimise these impacts to make energy more appealing to consumers. Jones and Dodds (2017) also note that the definition based on the four "As" has been criticised by other researchers as the definition focuses on some specific aspects of the concept. They added that governments often approach energy security from both engineering and geopolitical standpoints. The engineering perspective prioritises the safe and dependable functioning of energy technologies, while the geopolitical perspective has traditionally centred on ensuring a secure supply of resources. However, recent academic studies have sought to expand the concept of energy security to encompass the entirety of the energy system, spanning from the acquisition of primary energy resources to the ultimate consumption of energy.

These and several other definitions of energy security highlight the evolving understanding of the concept in response to environmental concerns, market dynamics, and geopolitical factors, emphasising the importance of comprehensive strategies to ensure sustainable and secure energy systems.

2.1.4 Scenarios

Scenario planning has emerged as a preferred approach in long-term energy forecasting, as it facilitates policy deliberations under uncertainty (IPCC, 2014; Spaniol & Rowland, 2019). Baseline, mitigation, and transformation scenarios each reveal different dimensions of risk, opportunity, and trade-offs in policymaking. The literature emphasises that scenarios should not be confused with forecasts; rather, they are structured tools for interrogating and stress-testing policy pathways. Most critiques point to weak stakeholder integration and insufficient representation of disruptive variables in scenario construction for the Ghanaian context.

Scenarios may be defined as descriptions of possible events or as narratives. This definition sheds light on the significance of foreseeing diverse results and preparing for varied circumstances. Scenarios serve the purpose of describing the existing state or behaviour of a system or environment, as well as the desired behaviour within that system or environment.

Spaniol & Rowland (2019) emphasised that scenarios are inherently future-oriented and should be characterised as potential and credible narratives. They recalled that scenarios are different from forecasts, prognoses, and visions. Similarly, the Intergovernmental Panel on Climate Change

(IPCC) defines scenarios as plausible descriptions of how the future may unfold, based on a consistent set of assumptions about key driving forces and relationships. The IPCC emphasises that scenarios are not predictions or forecasts; rather, they are used to offer insights into the potential implications of various developments and actions.

In the climate change discourse, four types of scenarios are acknowledged: baseline scenarios, emission scenarios, mitigation scenarios, and pathways. In the climate change discourse, several scenarios are acknowledged: baseline scenarios, emission scenarios, mitigation scenarios, pathways, etc. Each of these scenarios provides a different perspective on potential future outcomes. The baseline scenarios outline what is likely to happen if no changes are made to current trends. The emission scenarios, on the other hand, outline potential future outcomes based on different levels of greenhouse gas emissions.

The IPCC defines baseline scenarios as projections that assume no additional policies or measures beyond those already in effect or intended to be adopted. These scenarios are not meant to predict the future, but rather to illustrate the level of emissions that would occur without further policy efforts. Baseline scenarios are often compared to mitigation scenarios, which aim to achieve specific objectives related to greenhouse gas emissions, atmospheric concentrations, or temperature change. Mitigation scenarios provide credible portrayals of the future, showing how the system responds to the implementation of mitigation policies and procedures. Emission scenarios, on the other hand, depict the future progression of radiatively active substances, such as greenhouse gases and aerosols. These scenarios are based on a coherent set of assumptions about the factors influencing emissions, such as demographic and socio-economic developments, technological progress, and shifts in energy and land use. The scenarios also account for the key relationships between these driving forces.

2.1.5 Energy Demand and Supply

The role of energy resources in modern society is vital to the functioning of virtually every aspect of our daily lives. From powering our homes and businesses to fuelling our cars and planes, energy resources are essential for maintaining our standard of living. As energy demand continues to grow, alternative sources, such as renewable energy, are required to meet the demand for power and transportation, among other needs, and to ensure a sustainable future for generations to come. Consequently, the concepts of energy supply and demand cannot be underestimated, as they are critical components of society's functioning. It is crucial to carefully consider how these concepts interact to address environmental concerns and ensure sustainability.

Energy supply refers to the availability of energy resources for future use, while energy demand represents the requirement for energy to power various activities and functions. According to the EIA, energy supply is the energy made available for future disposition; energy demand, on the other hand, refers to the requirement for energy as a whole. This underscores the notion that there is a need for a balance between energy supply and demand, which is critical for ensuring a stable and sustainable energy system.

Energy demand is looked at from different perspectives to identify trends and patterns, ultimately helping to inform energy policies and strategies: primary energy demand (PED) and final energy demand (FED). Primary energy demand is the total energy demand required for all energy sources before any transformation or conversion, while final energy demand is the energy demand that is required by end-users for consumption after all losses and inefficiencies have been considered. Final energy demand is a key metric for understanding the true energy requirements of a society and the amount of energy supply needed to meet those demands. Interestingly, there are instances where energy demand may exceed supply, leading to shortages and potential disruptions in energy access.

Similarly, energy supply is looked at as primary energy supply (PES) and final energy supply (FES). Primary energy supply is the total amount of energy available from all sources, including fossil fuels, renewable energy, and nuclear power, before any conversion or transformation. Final energy supply, on the other hand, considers losses and inefficiencies in the energy supply chain, providing a more accurate picture of the actual energy available for end-users. In other words, FES is the energy that is available to consumers for use. The interconnected nature of FED, FES, PES, and PED underscores the complexity of modern energy systems; hence, they help in understanding the entire energy system and its impacts on greenhouse gas emissions and the overall sustainability of the energy sector.

Global energy demand is continuously increasing due to population growth and economic development. Data from Statista (2024) indicates that the global energy demand as of 2022 is 604 exajoules, which is equivalent to approximately 170,000 terawatt-hours, with fossil fuels accounting for over 80% of the demand. According to the IEA (2021), fossil fuels made up over 81% of global energy production, with coal being the primary fuel for power generation in 2019, contributing to 37% of global electricity production. The share of coal in power production had been around 40% since the mid-2000s, but it started declining in 2015 due to the rapid growth of renewables. Renewables surpassed natural gas in electricity production in 2013 and have continued to widen the gap, contributing almost 27% of global electricity and outpacing natural gas by three percentage points (24%) in 2019. The share of nuclear power has remained relatively stable at around 10% for eight years, while oil accounted for less than 3% of global electricity in 2019.

However, in 2020, energy supply from fossil fuels decreased by 5% relative to 2019 figures due to the COVID-19 pandemic and subsequent economic slowdown.

However, the supply of energy is struggling to keep up with the demand, leading to concerns about energy security and reliability, especially in Africa. For instance, in countries like Nigeria and Ghana, frequent power outages and blackouts are common due to insufficient energy supply compared to the high demand. This hinders economic development and affects the quality of life for citizens who rely on energy for necessities such as lighting, heating, and communication.

Nevertheless, renewable energy has been proliferating, with an average annual increase of about 20% in the 2010s insufficient energy supply. The IEA (2024) indicated that advances in wind generation (+11.5%) and solar power (+15.8% year-over-year) helped renewable sources continue to grow at a 7.0% annual rate in 2023. The main drivers of this growth have been government policies and advancements in renewable energy technologies, such as improved and efficient solar panels and wind turbines, the decreasing costs of renewable energy sources, and tax incentive policies on renewable energy adoption by individuals and organisations. However, the main challenge for renewable energy sources is the intermittency of their supply.

It is therefore imperative to consider both final energy demand and final energy supply to accurately assess the efficiency and sustainability of energy systems, as they provide different perspectives on energy availability and consumption in an era where energy security tends to be an emerging issue. Focusing solely on one aspect may lead to overlooking important factors that affect overall energy usage and emissions.

2.2 Theories and Concepts of Energy Demand and Supply

Theoretical frameworks for modelling energy demand and supply are wide-ranging, from economic optimisation and techno-economic modelling to sociotechnical transitions, practice theory, and systems thinking (Sorrell, 2015; Edomah et al., 2017; Geels, 2002). The Ghanaian literature predominantly focuses on top-down, quantitative approaches, often neglecting household-level decision-making, institutional inertia, or the politics of technological change (Agyekum, 2020). The growing literature on sociotechnical transitions advocates for integrating policy, markets, technology, and societal factors within a dynamic framework—an area still underdeveloped in the context of West Africa.

2.3 Energy Supply and Demand in Ghana: Trends and Drivers

Empirical evidence from national statistics demonstrates a marked rise in energy consumption, with household, transport, and industrial sectors being the principal drivers (Energy Commission, 2023). Yet most studies are fragmented, focusing on single fuels, short time horizons, or isolated geographic regions, thereby underestimating cross-sectoral feedback and co-benefits (Abledu, 2013; Nyasapoh et al., 2023). Recent research highlights the challenge of data scarcity and unreliability, which complicates both model calibration and scenario validation (Mukoro et al., 2021; Gebremeskel et al., 2023).

Recent demographic shifts, urbanisation, population growth, and changing household structures are expected to exacerbate energy demand surges in Ghana, creating risks of energy insecurity and intermittent supply crises if left unaddressed (Quartey, 2023a; Wang & Azam, 2024).

2.4 Ghana's Energy Sector Policy and Institutional Landscape

The policy environment in Ghana has become more supportive of renewable energy and energy efficiency through frameworks such as the Strategic National Energy Plan (SNEP), Renewable Energy Master Plan, and Nationally Determined Contributions (NDCs). However, persistent policy fragmentation, gaps in enforcement, coordination failures, and political economy factors (e.g. subsidy regimes, incumbent interests, grid constraints) limit effective implementation. Comparative studies suggest that Ghana's policy mix lags behind countries such as Kenya or Morocco in transitioning to renewables (IRENA, 2021), and that political will, coupled with access to climate finance, will be decisive for accelerated change (Agyekum et al., 2021).

2.5 Integrated Energy Modelling Tools and LEAP Application

The LEAP model, developed by SEI, has become widely used for integrated scenario analysis in energy and environment studies, valued for its accessibility, modularity, and ability to accommodate both bottom-up and top-down inputs (Huang et al., 2010; Ugwoke et al., 2021). In Ghana, its application is still limited relative to peers, with most prior studies using simpler accounting or optimisation models. Notably, Amo-Aidoo et al. (2022) and Awopone & Zobaa (2017) demonstrate how LEAP-based scenarios can test policy mixes which combine renewable energy penetration, efficiency standards, and transport sector interventions, with significant projected emissions savings.

Nevertheless, shortcomings remain; scenario modelling often omits price effects, endogenous technological change, behaviour adaptation, and sensitivity checks, elements essential for realistic planning. LEAP is also rarely "soft-linked" with other models such as MESSAGE or OSeMOSYS in local studies, which constrains multi-criteria and cost-optimisation analyses (Gebremeskel et al., 2023). There is a further lack of explicit integration between LEAP's outputs and non-energy sector goals (employment, land use, health), despite the increasing literature advocating multi-sectoral approaches (Rivera-González et al., 2019; Dranka et al., 2021).

2.6 Gaps and Controversies in the Ghanaian and African Literature

Critical gaps

- Comparative analyses of different modelling tools and scenario outcomes for Ghana and similar economies are rare, making benchmarking difficult (Nyasapoh et al., 2023).
- Little critique or comparison exists regarding how different methodological approaches address uncertainty, equity, or technology adoption.Report-1_-27-05-25.pdf
- Policy debates over equity, gender impacts, regional disparities, and politics of grid access are underexplored in the context of Ghanaian energy transitions (Sovacool et al., 2011).
- Most studies are strong on describing trends but weak on synthesising lessons and generating actionable knowledge for targeted stakeholders (IRENA, 2021; Sorrell, 2015).

Controversies highlighted in international debates and increasingly relevant for Ghana include:

- The degree to which nuclear or "clean coal" options should be considered for energy security versus investments solely in renewables.
- The extent to which market mechanisms, such as carbon pricing, can be effectively implemented in developing economies facing fiscal constraints and social opposition (Dranka et al., 2021).
- Risks of overreliance on external financing and donor-driven priorities at the expense of context-specific solutions (IRENA, 2021).

2.7 Positioning the Study and Synthesis

This study addresses the identified deficiencies by:

- Applying a LEAP-based scenario analysis that tightly integrates sectoral energy, emissions, and policy dynamics relevant to Ghana's development and climate commitments.
- Critically engaging with both theoretical and empirical streams—from energy security and sociotechnical transitions to stakeholder-centred scenario design—rather than restricting itself to technical modelling alone.
- Benchmarking findings and scenario assumptions against both national (e.g., SNEP, NDCs) and international best practices, with explicit recognition of Ghana's unique socio-political realities.
- Highlighting where methodological and data constraints could affect policy translation and identifying avenues for further research, such as model validation, expert review, and triangulation with observed trends.

2.8 Historical Energy Consumption in Ghana

The energy sector in Ghana is characterised by a blend of renewable and non-renewable sources, with fossil fuels playing a predominant role in fulfilling the country's energy needs. The balance between energy supply and demand has been a topic of discussion since Ghana gained independence in 1957. In the early 1990s, hydro and thermal power plants were Ghana's primary energy sources, adequately meeting the population's needs and industrial activities at that time. However, looking ahead to the 2000s, Ghana's energy demand surged considerably, attributed to population growth and ongoing industrialisation. Energy from fossil fuels in various forms became the primary source of power generation in Ghana, leading to concerns about environmental impact and sustainability.

According to the Energy Commission (2023), oil (average of 2,347 ktoe representing 37.2%) and biomass (average of 3,465 ktoe representing 55.4%) constituted the majority of Ghana's energy supply, with hydropower (average of 464 ktoe representing 7.4%) making up a small percentage of the total from 2000 to 2008. During this period, Ghana did not have natural gas or solar in its energy mix; however, natural gas and solar were introduced into the mix in 2009 and 2013, respectively. In recent years, there has been a gradual increase in the share of natural gas and solar energy in Ghana's energy mix. Solar energy has risen from 0.1 ktoe (approximately 0% of the total energy supply) to 14 ktoe (0.11% of the total energy supply) in 2022, while natural gas has increased from 5 ktoe (0.1% of the total energy supply) to 3,472 ktoe (28.2% of the total energy supply) between 2008 and 2022. Natural gas, however, saw a massive decline in 2013, dropping from 796 ktoe in 2011 to 292 ktoe.

The total energy supplied has increased from 6,146 ktoe in 2000 to 12,331 ktoe in 2022, with an average annual growth rate of 3.2%. In 2021, crude oil accounted for 37% of the primary energy supply, followed by biomass (30.3%), natural gas (27.1%), and hydropower (5.5%). While the use of natural gas and modern renewable energy sources is on the rise, biomass still plays a significant role in the energy mix, despite its share declining from 38.3% in 2018 to 30.3% in 2021 (Quartey, 2023b; Energy Commission, 2023). In 2022, crude oil's share decreased to 33.6%, while natural gas, solar, and biomass increased.

Driven by population growth, industrialisation, and economic expansion, the total final energy consumption has steadily increased from 5,470 ktoe in 2000 to 8,537 ktoe in 2022, with an average annual growth rate of 2.2%. This upward trend in energy consumption is projected to persist in the years to come. In Ghana, the sectors that are in high demand for energy are residential or household, transport, industry, service, and agriculture. The residential sector consumes the most energy, with an annual average of about 43% from 2007 to 2022, then the transport sector (36%), the industry (15%), the service sector (4.3%), and the agriculture sector (1.3%). However, in 2021 the transport sector consumed the most energy (40.4%) due to an increase in demand for personal vehicles, and the residential sector experienced a decline of 4% (making it 36% of the total), whereas the industrial sector (18%), the services sector (4%), and the agriculture sector (1.7%) increased relative to that of 2020. In 2022, the residential sector increased by a 1% margin compared to the previous year, making it the sector with the highest share.

Biomass fuels for cooking and petroleum products for transportation, respectively, dominate energy consumption in the residential and transportation sectors, and energy consumption in the residential sector is primarily due to heating and cooling needs. Ghana has made significant progress in expanding access to electricity, with over 88.8% of the population now connected to the grid (Energy Commission, 2023). However, universal access to clean energy remains a challenge, particularly in the clean cooking sector, where only 29% of Ghanaians rely on clean cooking fuels and technologies (Ghana Statistical Services, 2022). The majority still rely on traditional biomass sources such as firewood and charcoal, contributing to indoor air pollution and health issues. The need for the processing, storing, and transportation of goods and services is what primarily drives energy usage in the agricultural and service sectors.

Table 2.8.1 Final energy consumption by fuel type from 2007 to 2022

	Electricity		**Petroleum**		**Biomass**		**Total**
	Ktoe	**%**	**Ktoe**	**%**	**Ktoe**	**%**	**Ktoe**
2007	539	10.4	2,023	39.1	2,614	50.5	**5,176**

2008	621	12.1	1,973	38.4	2,544	49.5	**5,138**
2009	641	11.3	2,496	44.2	2,513	44.5	**5,650**
2010	715	13	2,408	43.6	2,395	43.4	**5,518**
2011	790	13.4	2,704	45.7	2,419	40.9	**5,913**
2012	796	12.2	3,189	48.7	2,566	39.2	**6,551**
2013	910	13	3,308	47.1	2,804	39.9	**7,022**
2014	920	13.1	3,243	46.2	2,853	40.7	**7,016**
2015	914	12.5	3,497	47.9	2,896	39.6	**7,307**
2016	1,077	14.8	3,255	44.7	2,945	40.5	**7,277**
2017	1,121	15.4	3,103	42.6	3,053	42	**7,277**
2018	1,150	14.8	3,581	45.9	3,063	39.3	**7,794**
2019	1,226	15.2	3,793	46.9	3,069	37.9	**8,088**
2020	1,327	15.4	4,248	49.4	3,026	35.2	**8,601**
2021	1,453	16.6	4,641	53	2,660	30.4	**8,754**
2022	1,509	17.2	4,318	49.3	2,940	33.5	**8,767**

Source: 2023 Energy Statistics of Ghana

2.9 Demographic Trends and Their Implications for Energy Demand in Ghana

The demographic landscape of Ghana has undergone significant transformation over the past decades, marked by rapid population growth, changing age structures, and accelerated urbanisation. These dynamics profoundly shape the trajectory of energy demand and consumption patterns, underscoring the necessity of incorporating demographic variables into energy forecasting.

Ghana's population surged from approximately 6 million in 1957 to nearly 31 million by 2021, reflecting an average growth rate of about 2.1% per annum, which is projected to persist into the mid-21st century (Ghana Statistical Service, 2022; Quartey, 2023a). This sustained population increase presents critical challenges for energy infrastructure, as rising household numbers and socio-economic diversification escalate energy needs.

The population age structure remains notably youthful, with a significant share—roughly 36%—under the age of 15 (GSS, 2022). This youth bulge portends further increased demand in the coming decades as this cohort enters the workforce, amplifying residential, commercial, and transport-related energy consumption (Awunyo-Vitor et al., 2019). Simultaneously, the fertility rate has declined from 6.4 births per woman in the late 1980s to about 3.8 in 2021, signalling a gradual demographic transition with potential long-term moderating effects on energy demand growth (Quartey, 2023a).

Rapid urbanisation further compounds energy demand pressures. Ghana's urban population has grown from about 50% in 2010 to over 58% in 2021, with metropolitan areas like Accra and Kumasi experiencing intense spatial expansion (GSS, 2022; Cobbinah & Erdiaw-Kwasie, 2018). Urban growth engenders shifts in energy consumption typologies, favouring increased use of electricity and liquid fuels for appliances, transport, and commercial activities, while also introducing complexities related to unregulated peri-urban development and infrastructure strain (Sundqvist & Yaro, 2014).

Notably, disparities between urban and rural energy access and consumption remain pronounced. While over 88% of Ghanaians have access to electricity nationally, rural electrification lags behind, with traditional biomass fuels dominating household energy use, resulting in significant health and environmental externalities (Ghana Statistical Services, 2022; Edomah & Ndulue, 2019).

These demographic shifts intersect with economic growth patterns and lifestyle changes, including increased appliance ownership, vehicle usage, and transmission of urban consumption behaviours to rural areas, cumulatively escalating aggregate energy demand (Manda et al., 2020). Therefore, energy forecasting models must robustly integrate demographic projections, urbanisation trajectories, and associated socio-economic variables to enable accurate and policy-relevant scenarios.

In the broader context, these demographic realities emphasise the need for inclusive energy policy frameworks that address equitable access, affordability, and resilience, especially amidst climate vulnerabilities and socio-economic disparities (Acheampong et al., 2020; Lin & Ockwell, 2017).

2.10 Ghana's Greenhouse Gas Emissions

Climate change is a global threat as it causes rising sea levels, extreme weather events, and disruptions to ecosystems in diverse regions (Malhi et al., 2020). It is widely acknowledged through scientific research that while natural events like volcanic eruptions, earthquakes, and solar flares play a role in climate change, the primary cause is attributed to anthropogenic greenhouse gas emissions ("Why is Climate Change Happening and What Are the Causes?", 2013). Human activities such as the combustion of fossil fuels, deforestation, and industrial processes release greenhouse gases into the atmosphere, resulting in the trapping of heat and contributing to global warming. These activities are dispersed across different regions, but collectively they have profound consequences on a global scale. Data indicates that the majority of these activities are concentrated in the global north as opposed to the global south.

Ghana, a country in the global south, for instance, contributes a negligible percentage of global emissions compared to some other African countries, while countries in the global north, like the

United States and China, are responsible for a much larger percentage (Tetteh & Baidoo, 2022). In contrast, Ghana's greenhouse gas (GHG) emissions have been steadily increasing over the past three decades, with a significant growth rate of 5.1% per annum from 1990 to 2021. According to the country's greento the UNFCCC (2024), Ghana's total net greenhouse gas emissions in 2021 were 51.78 million tonnes of carbon dioxide equivalent ($MtCO_2e$), representing a 12% increase from the 2019 levels.

The 2019 National Greenhouse Gas Emission Report highlighted that carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) were the most prevalent greenhouse gases, accounting for 70.1%, 14.3%, and 13.7% of total emissions, respectively. The report further noted that in 2021, CO_2 contributed to 63.3% of total national emissions, followed by CH_4 (17.9%), and N_2O (15.9%), with smaller contributions from hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6). The 2021 Greenhouse Gas Emission Report revealed that the majority of emissions in Ghana originated from the energy sector (45.7%) and agriculture, forestry, and other land use (44.6%). However, the Fourth Biennial Update Report to the UNFCCC in 2024 indicated that Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), Industrial Processes and Product Use (IPPU), and the Waste sectors also significantly contributed to the country's emissions. The report also indicated that Ghana's emissions profile is dominated by the energy sector and has remained the largest greenhouse gas emissions source since 2010, which, on average, contributed 41% to the total national emissions, with transportation, other fuel combustion, and electricity and heat being the main sources of emissions within the sector. Consequently, in 2021, the sector breakdown of the total emissions amounted to 51.2% from the energy sector, followed by Agriculture, LULUCF Waste, and IPPU with 23%, 15.3%, 7.3%, and 3.2% respectively. The agricultural sector plays a significant role in emissions, with burning savannas being responsible for nearly half of the agricultural emissions and the waste sector with methane emissions from waste disposal accounting for 36.2% of the national total.

The country has taken significant steps to address climate change and reduce greenhouse gas emissions. It has implemented policies such as the National Climate Change Policy (NCCP) to enhance national greenhouse gas inventory mechanisms and implement measures to cut emissions. The country has committed to decreasing its unconditional greenhouse gas emissions by 15% by 2030 as compared to the BAU scenario, with an additional pledge to cut an extra 30% if supported internationally. The revised Nationally Determined Contributions (NDC) demonstrate increased ambition, aiming to reduce emissions by 64 Mt of CO_{2e} by 2030. The updated NDC outlines 47 strategies the country plans to undertake, considering their socioeconomic impacts, employment opportunities, funding, number of beneficiaries, and gender considerations.

Table 2.10.1 Trends of greenhouse gas emission by sector and total GHG emissions trends per sector for 1990-2021

Emission by source/Removal by sink	**Total emissions ($MtCO_{2e}$)**							**Percentage Change**
	1990	**2000**	**2010**	**2012**	**2016**	**2019**	**2021**	**[2019-2021]**
National Emissions with LULUCF	10.96	20.68	30.62	35.09	33.68	46.42	51.78	16%
National Emissions without LULUCF	8.74	111.93	22.42	26.12	28.82	36.12	42.21	19%
Energy	2.86	4.07	10.82	13.64	14.06	19.36	26.52	22%
Industrial Processes and Product Use	1.96	0.9	0.94	2.02	1.69	1.82	1.66	3%
Agriculture, Forestry, and Other Land Use	5.11	14.23	15.85	16.21	13.68	20.37	19.83	11%
Waste	1.02	1.48	3.01	3.23	4.25	4.87	3.77	13%

Source: The Fourth Biennial Update Report (2024)

2.11 The role of the Low Emission Analysis Platform (LEAP) in Ghana's energy sector

The Low Emission Analysis Platform (LEAP), formerly known as the Long-Range Energy Alternative Planning System, has played a pivotal role in modelling potential demand scenarios for the country's future energy needs. The LEAP software has been utilised to create scenarios such as Business-as-Usual (BaU) and Accelerated Economic Growth (AEG), aligning with the objectives of the Ghana Shared Growth and Development Agenda and the Coordinated Programme of Economic and Social Development Policies (Energy Commission, 2019; "Strategic National Energy Plan", 2006, 2019). These scenarios provide valuable insights into the potential trajectories of energy demand and supply in Ghana as seen in the Strategic National Energy Plans (SNEPs); SNEP I (2006 to 2020) and SNEP II (2020 to 2030). Additionally, some researchers in Ghana have employed the LEAP in various studies and provided insight into energy demand and supply analysis. A few of these studies have been highlighted in the literature review of this study.

2.12 Existing Literature on Energy Demand and Supply and Emissions

The empirical literature on energy demand and supply covers a range of studies that shed light on various facets of global efforts to combat climate change through mitigation measures. These studies offer valuable insights into energy production and consumption and their impact on greenhouse gas emissions, environmental sustainability, and energy security. However, there are still notable gaps in our understanding.

The Low Emission Analysis Platform (LEAP) model is a widely used software tool that helps to monitor energy consumption, production, and resource extraction across all sectors of the economy. It employs scenario-based modelling to facilitate energy policy analysis and climate change mitigation assessment on various scales, from local to global. LEAP supports multiple modelling methodologies and is widely adopted by government agencies, academic institutions, nonprofits, consulting firms, and energy utilities in almost 190 countries.

Consequently, a study conducted by Amo-Aidoo et al. (2022) delved into the utilisation of the Low Emissions Analysis Platform (LEAP) to simulate the advancement of solar energy in Ghana. It demonstrated how well-crafted renewable energy policies can act as catalysts for the growth of solar energy within the country. The analysis presented various electricity demand and supply scenarios, illustrating the potential for substantial solar integration by 2030. This integration could lead to widespread access to electricity and a reduction in carbon emissions. Furthermore, the paper underscored the significance of scaling up renewable energy deployment initiatives to align with global climate change mitigation objectives, such as those articulated in the Paris Agreement. The study utilised historical data to forecast demand and supply between 2019 and 2030, with a specific focus on the potential role of solar energy in Ghana's energy portfolio. Additionally, it addressed the principal challenges influencing the execution of solar energy projects in Ghana, per international standards and energy policy considerations.

A paper titled "An Overview of Energy Resource and Future Concerns for Ghana's Electricity Generation Mix" by Nyasapoh et al., (2022b) provided a qualitative review of Ghana's energy resources and their impact on the future electricity generation mix. It highlighted that Ghana mainly relies on hydro, natural gas, and solar energy for electricity generation. The study emphasised the need for sustainable energy options and policies to ensure a resilient and sustainable electricity generation mix. It also discussed the existing and potential energy resources available for sustainable electricity generation in Ghana. It furthermore offered valuable insights into the dynamics of electricity generation in Ghana and the importance of transitioning to newer and cost-competitive energy sources to modernize the national grid and ensure sustainable energy development.

Another study conducted by Nyasapoh et al. (2023) titled "Long-term Electricity Generation Analysis and Policy Implications – the Case of Ghana" utilised the International Atomic Energy Agency - Model for Energy Supply Strategy Alternatives and their General Environmental Impact (IAEA MESSAGE) Analytical tool to quantitatively assess the electricity generation in Ghana from 2020 to 2048. The study aimed to create a cost-effective and low-carbon electricity generation environment. The methodology of the study was based on the LEAP model, and it examined the impact of various electricity generation scenarios on the environment and the economy. The findings emphasised that increasing the use of renewable energy sources and low-carbon options, such as nuclear power, is the most effective long-term strategy for reducing CO2 emissions from the energy industry. The study also emphasised the need for a thorough assessment of environmental consequences and expenses to attain a power generation combination that incorporates coal. It is projected that coal consumption will make up 70.7% of the energy mix, while gas will account for 29.3% by 2048. Furthermore, the implementation of energy policy should be led by a dedication to achieving a sustainable and enduring mix of electricity-producing methods. By 2048, the research indicated that adopting a diversified power production strategy will lead to a significant 32.30% cost reduction and a substantial 55.27% decrease in CO_2 emissions. In contrast, following an accelerated economic growth (AEG) scenario will result in a 12.21% increase in cost and a 21.10% rise in CO_2 emissions.

A study by Awopone & Zobaa (2017) examined the optimal generation scenarios for Ghana from 2010 to 2040 using the Open Source Energy Modelling System (OSeMOSYS) integrated with the Long-range Energy Alternatives Planning (LEAP) tool. The study aimed to develop the least-cost generation pathways for the generation system of Ghana, considering the available technologies, policy drivers, and challenges in Ghana. The paper presented three groups of policy scenarios based on future possible energy policy directions, energy emission targets, efficiency scenarios, and transmission and distribution losses scenarios. The study provided useful insights to guide energy planners and policymakers by providing a policy impact assessment of the optimum generation system of Ghana. The paper emphasises the importance of promoting renewable power generation in Ghana to achieve sustainable power generation and reduce greenhouse gas emissions.

In a study conducted by Huang et al. (2010), the LEAP application was utilised within Taiwan's energy framework. The study delved into the long-term forecasting of energy supply and demand in Taiwan, the historical evolution and the current status of its energy policies. It also explored the use of the Long-range Energy Alternatives Planning System (LEAP), now known as the Low Emission Analysis Platform model, to compare future energy demand and supply patterns, as well as greenhouse gas emissions, under various alternative scenarios of energy policy and energy sector evolution. The paper provided an analysis of Taiwan's energy status, covering energy supply, energy demand, and CO2 emissions. It offered an overview of Taiwan's energy landscape, highlighting its dependence on energy imports and the government's efforts to establish a sustainable energy demand and supply system, focusing on energy security, environmental protection, and economic competitiveness. The study also emphasised the challenges and opportunities in Taiwan's energy sector, such as the need for energy efficiency improvements, the impact of lower economic growth assumptions, and the implications of model results for future energy and climate policies in Taiwan.

In a study conducted by Foday et al. (2023), the LEAP model was utilised to provide a long-term forecast of Sierra Leone's energy supply and demand from 2019 to 2040, focusing on establishing a Sustainable Power Generation System. The study considered three scenarios: Base, Middle, and High. The Base case depicted the business-as-usual scenario, while the Middle case analysed the electricity sector reform roadmap and the integration of renewable energy. The High case prioritised sustainable development, integrating renewable energy and the electricity sector reform roadmap. The findings revealed an increase in electricity demand of 1812.5 GWh, 1936 GWh, and 2635.8 GWh for the Base, Middle, and High cases, respectively. Moreover, the High case demonstrated a significant decrease in production, fuel cost, and CO2 emissions in comparison to the Base case by 67.15%, 35.79%, and 51.8%, respectively. This underscores the potential for sustainable energy systems when integrating renewable energy sources and technologies with lower CO_2 emissions. The study recommended the implementation of the electricity sector reform roadmap to enhance efficiency and sustainability, along with the establishment of partnerships with the private sector to ensure a sustainable and inclusive electricity supply public service. Additionally, the study emphasised the necessity of addressing the diverse needs of Sierra Leone's population and business community at both national and local levels.

Similarly, in their 2019 study titled "Long-Term Electricity Supply and Demand Forecast (2018–2040): A LEAP Model Application towards a Sustainable Power Generation System in Ecuador," Rivera-González et al. conducted a comprehensive analysis of the long-term electricity supply and demand forecast for Ecuador using the Long-range Energy Alternatives Planning (LEAP) model. The primary objectives of the study were to examine possible alternatives for electricity supply and demand, fuel consumption, and the future structure of the Ecuadorian power generation system, with a focus on transitioning from a system based on petroleum fuels to one that progressively integrates renewable power generation plants such as solar, wind, biomass, and hydroelectric sources until 2040. The researchers developed three potential alternative scenarios using the LEAP model: S1 (Business as Usual), S2 (Power Generation Master Plan), and S3 (Sustainable Power Generation System). The study found that under the S3 scenario, which incorporates sustainable energy policies, the average CO_2 equivalent (CO_{2e}) emissions could be reduced by 11.72% compared to the S1 scenario. The study provided detailed projections of electricity demand growth in Ecuador under the three scenarios, indicating a significant increase in net electricity demand from 20,204 GWh in 2017 to 44,847 GWh in 2040 under the S1 scenario, 64,728 GWh in 2040 under the S2 scenario, and 72,053 GWh in 2040 under the S3 scenario. Furthermore, the researchers analysed the potential changes in the electricity generation mix, noting a substantial increase in the share of renewable energy sources, such as solar, wind, and hydroelectric power, to meet the growing electricity demand more sustainably, particularly under the S3 scenario.

A study titled "Low emissions analysis platform model for renewable energy: Community-scale case studies in Nigeria" by Ugwoke et al. (2021) focused on community-scale energy planning in rural communities in Nigeria using the Low Emissions Analysis Platform (LEAP) model. The study modelled the long-term energy demand and supply evolution from 2015 to 2040 in the rural communities of Onyen-okpon and Giere. It explored the synergies between community planning and energy planning strategies, which is an under-investigated area, particularly in the developing world. The paper also provided valuable insights into renewable energy modelling and planning at the community level, emphasising the importance of sustainable energy solutions for rural areas in Nigeria.

The LEAP model has been used in several studies to forecast energy demand and develop electricity generation scenarios for Ghana. These studies have analysed the impact of different electricity generation scenarios on the environment, the economy, and the energy sector. The LEAP model is a useful tool for policymakers and energy planners to develop sustainable energy policies and strategies for Ghana.

2.13 Theoretical Framework

The study's theoretical frameworks are grounded in the application of the Low Emission Analysis Platform (LEAP) model to analyse and forecast electricity demand and supply scenarios for Ghana. The study will employ the LEAP model to create demand projections based on various scenarios, including business-as-usual (BAU) and renewable energy policy-driven scenarios (Amo-Aidoo et al., 2022; Energy Commission, 2019). It will also incorporate factors such as economic growth, population projections, and energy system simulation using the LEAP model to identify future energy supply constraints, policy issues, and sustainable transition options. The study's theoretical frameworks are grounded in using the LEAP model for long-term energy planning, scenario development, and policy analysis, focusing on sustainable energy transition and climate resilience (Nyasapoh et al. 2023).

2.14 Conceptual Framework

The conceptual framework presents a comprehensive view of the energy demand and supply projections in Ghana, with a specific focus on two main parameters: population growth and economic growth. It highlights the interconnectedness of the major aspects of this study and presents the four major sectors that play crucial roles in both energy demand and energy supply.

These sectors are closely linked to population growth, economic growth, energy demand, and energy supply in a way that they impact greenhouse gas (GHG) emissions. The LEAP analysis will consider the four main sectors along with population and economic growth. The analysis will be conducted based on two primary scenarios: the business-as-usual (BAU) scenario and the policy intervention scenario. These scenarios will then allow for the projection of future energy demand and supply, as well as the associated greenhouse gas emissions. Therefore, the main goal of this study is to forecast energy demand and supply in Ghana from 2023 to 2050, and to identify any existing gaps that require attention and resolution. By addressing these gaps, the study aims to offer evidence-based recommendations for policymakers and stakeholders in order to help Ghana achieve its emissions reduction targets.

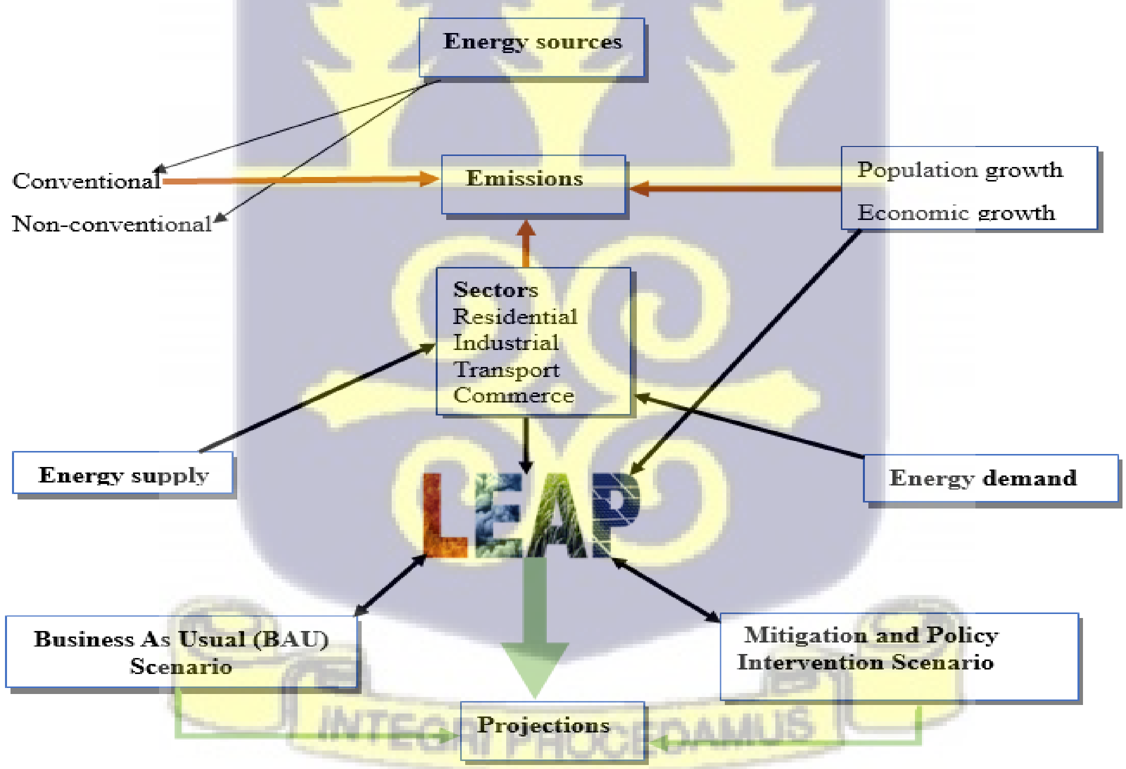

Figure 2.14.1: Conceptual Framework for the Study
Source: Researcher's construct

2.15 Energy Sources in Ghana

Conventional and non-conventional sources collectively form the backbone of Ghana's energy sector, with a notable predominance of conventional, particularly fossil fuels. The energy landscape in Ghana encompasses petroleum (crude oil, petroleum products, and natural gas), hydropower, biomass, solar, and wind resources. Electricity generation in Ghana is derived from a mix of hydropower, fossil fuels (thermal energy), and non-conventional sources like wind and solar ("Energy Outlook", 2023). As per the Energy Statistics (2023), the primary energy sources in 2022 include oil (33.6%), natural gas (28.2%), biomass (32.4%), and hydro (5.7%). Thermal generation, predominantly utilising natural gas, accounts for 66% of the installed capacity for electricity generation in Ghana, while hydropower contributes 33% ("Fourth Biennial Update Report", 2024). The transportation and industrial sectors in Ghana rely on a blend of energy sources, with fossil fuels such as gasoline and diesel being prominent, alongside some renewable options like biofuels. Similarly, energy consumption in agriculture and households is sourced from a variety of outlets, including biomass for cooking and heating, as well as electricity from the national grid.

2.15.1 Non-conventional Energy Sources

The Paris Agreement, adopted in 2015, aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels, preferably to 1.5 degrees Celsius, due to the adverse effects posed by climate change on the environment and human societies. The UNFCCC recognises that there is a need to tackle the issues of climate change through mitigation actions, adaptation measures, and international cooperation. To increase the ability of countries to deal with the impacts of climate change, the UNFCCC has tasked member countries to submit mandatory reports like the Nationally Determined Contributions (NDCs) and the Biennial Report. This has enabled the UNFCCC to identify the various sources of emissions and the intensity of the emissions in different countries. As such, the energy sector (predominantly fossil fuels) emerged as a major contributor to global emissions, which cause climate change. Consequently, the UNFCCC has been working with member countries to develop strategies to transition to cleaner and more sustainable energy sources, which include promoting renewable energy sources such as solar, wind, and hydropower, as well as encouraging energy efficiency measures.

Ghana, a member country of the UNFCCC, has been actively exploring alternative energy sources to diversify its energy portfolio and decrease its reliance on fossil fuels. In line with Sustainable Development Goal 7 and efforts to address climate change, the country has made significant strides in harnessing renewable energy from sources such as solar, wind, and biomass. Ghana's Updated Nationally Determined Contribution under the Paris Agreement (2021) delineates mitigation and adaptation measures, including a commitment to increase the share of renewable energy in the energy mix by 10% by 2030. Despite this, as of 2015, the total installed capacity of renewable energy for electricity stood at around 1,602 MW, constituting approximately 43.8% of the country's total installed electricity capacity.

2.15.1.1 Hydropower

Hydropower in Ghana has been one of the most reliable and clean sources of energy for the country, supplying a significant percentage of the nation's electricity needs. It has been a key factor in Ghana's efforts to reduce reliance on fossil fuels and decrease carbon emissions, as it has also played a crucial role in supporting economic development and improving access to electricity for communities across the country. Ghana has three main hydropower plants: the Akosombo Dam, the Kpong Dam (also known as the Akuse Dam), and the Bui Dam, with capacities of 1020 MW, 160 MW, and 404 MW, respectively (Energy Commission, 2022). The Akosombo Generating Station (AGS) and the Kpong Generating Station (KGS) are owned and operated by the Volta River Authority (VRA) and have been major sources of hydropower for the country, providing significant energy for residential and industrial use.

The Renewable Energy Master Plan (2019) indicated that hydropower in 2015 accounted for about 43.2% of Ghana's total electricity generation (43.8%) from renewable energy. Similar to this, the VRA (2021) stated that its hydroelectric capacity as of 2021 is 1180 MW, which represents 46.6% of Ghana's total installed capacity that the VRA produces and 22.6% of the total national capacity. In 2021, the Akosombo Generating Station (AGS) produced 5,557 GWh, which was 93 GWh (1.6%) below the planned generation of 5,650 GWh. In contrast, the Kpong Generating Station (KGS) generated 972 GWh, exceeding the planned generation of 850 GWh by 122 GWh (14.4%). The total hydro generation from VRA's sources was 6,530 GWh, which was 30 GWh (0.5%) higher than the planned generation of 6,500 GWh.

The Bui Dam, which is Ghana's second-largest hydropower project with a total generating capacity of 404 MW and operated by the Bui Power Authority, has been instrumental in increasing Ghana's hydrogeneration capacity. The Bui Generating Station (BGS) and the KGS generated a significant portion of the total power generated from hydroelectric sources. Efforts to further expand Ghana's hydroelectric power generation have led to the construction of a mini hydro plant, the Tsatsadu Generating Station (TGS), with a capacity of 45 kW by the BPA. This mini hydro plant is part of Ghana's strategy to diversify its energy sources and increase renewable energy capacity. The addition of the Tsatsadu Generating Station will contribute to Ghana's overall goal of achieving energy security and sustainability.

2.15.1.2 Solar

Ghana, located along the equator, has a substantial solar resource that is currently being harnessed for renewable energy production. This makes solar energy in Ghana increasingly popular as a sustainable and renewable energy source with great potential for growth in the future, which is beneficial for both the environment and the economy. The country started harnessing solar energy as a key part of its strategy to reduce its reliance on fossil fuels and decrease greenhouse gas emissions. The National Energy Statistics (2023) highlighted that the supply of solar energy in Ghana commenced in 2013 with a total supply of 0.3 ktoe (equivalent to 3489 MWh ~ 0.97 MW), which is quite negligible in the total energy mix of Ghana. However, the report also shows a promising increase in solar energy supply for 9 years (from 2013 to 2022). Solar energy supply remained at 0.3 ktoe in 2014 and 2015 but increased significantly to 14 ktoe in 2022, representing 0.11% of the total supply mix. The development of solar farms and the implementation of government incentives for renewable energy are driving forces behind this progress. Ghana currently has about six solar farms that are connected at the sub-transmission level, namely: Navrongo solar power station (2.5 MW), Lawra solar power station (6.5 MW), Kaleo solar power station (13 MW), BXC solar power station (20 MW), Meinergy solar power station (20 MW), and Bui solar power station (50 MW). The Navrongo, Lawra, and Kaleo solar power stations are all owned and operated by the VRA. While the BPA owns and runs the Bui power station, the BXC and Meinergy solar power stations are both privately owned and run. There are efforts to expand solar power production; as a result, the Nzema solar power station (250 MWp) is under construction. The BPA (2022) stated that the expansion of the Bui solar station is underway, which is expected to provide an additional 260 MW of power upon completion. Additionally, the VRA has plans to increase its solar energy in the mix by constructing similar stations in the future.

2.15.1.3 Biomass

Biomass in Ghana has been used as a source of energy for cooking and heating for centuries and continues to be an important part of the country's energy mix today. Biomass comes in various forms, like wood, agricultural residues, and animal waste, which can be used for biogas, briquettes, and pellets. The majority of Ghanaian households have depended solely on biomass as their primary source of energy for centuries. In the 2000s, the dependence of Ghanaian households on biomass as their primary source of energy began to decrease due to the introduction of more modern and efficient energy sources. Biomass consumption experienced a decline at a rate of 0.7% from 2000 to 2022; despite that, it was the dominant source of energy from 2000 to 2012 until oil emerged as the most dominant source in 2013 (National Energy Statistics, 2023). However, due to the abundance of biomass in the country, biomass continues to be used as a secondary energy source in many rural areas of Ghana.

Biomass is the second largest energy source currently, as it accounted for 32.4% of the energy sources listed and was paramount to the significant increase in the energy supply in 2022 relative to 2021 figures (National Energy Statistics, 2023). Wood for firewood and wood for charcoal were the main contributors to the biomass energy source in Ghana and declined at a rate of 0.1% from 2000 to 2022. Wood fuel consumption was driven by demand from residential (88.2%), industry (8.3%), and service (3.5%).

A comprehensive review of biomass resources and biofuel potential by Duku et al. (2011) found that Ghana has the potential to produce significant amounts of biofuel from its abundant biomass resources. This suggests that biomass could continue to play a significant role in Ghana's energy mix in the future, especially as the country seeks to reduce its reliance on fossil fuels and move towards more sustainable energy sources. In contrast, Mawusi et al. (2023) did a comprehensive review of the production, adoption, and sustained use of biomass pellets in Ghana and found that the production of pellets can significantly replace traditional household biomass demand and improve environmental and health quality; however, the production and use of pellets are limited due to technical, financial, social, and policy issues.

Despite the impractical nature of biomass pellets, other forms of biomass sources, such as wood, agricultural residues, and animal waste, are being utilised as alternative sources of renewable energy. Briquette production from agricultural waste is a more practical and effective solution for biomass energy generation; hence, its adoption by individuals is steadily increasing.

2.15.1.4 Wind

Ghana possesses a substantial quantity of wind energy resources that can be utilised to produce power and enhance the country's energy composition. The country has a wind potential of about 5563 MW, and the regions with the highest wind energy potential are the eastern area, Greater Accra, sections of the Volta region, and the Ashanti region; however, further analysis indicated that Ghana's untapped exploitable wind energy ranges from 200 MW to 300 MW (Kabu, 2016; Essandoh et al., 2014). These regions see wind velocities of about 6 m/s and above, making them ideal for the establishment of large-scale wind farms, and the country in general possesses a geographical capacity of 8.5% of its total available land area for the generation of wind energy, which makes it an advantageous terrain for the implementation of wind energy projects. The increased investments in wind energy infrastructure and technology in Ghana have been instrumental in the country's efforts to diversify its energy sources, reduce reliance on traditional fossil fuels, meet renewable energy targets, and address the impact of climate change. The government of Ghana has implemented policies and incentives to attract investment in wind energy projects following thorough assessments and feasibility studies. These initiatives have further contributed to the growth of the sector and the achievement of sustainable development goals, aligning with Ghana's NDCs for wind energy. Additionally, efforts have been made to utilise wind resources for purposes such as irrigation through projects like the installation of Poldaw wind pumps in various regions. However, challenges such as initial costs, limited expertise, and maintenance equipment have hindered the widespread promotion of this technology.

Ghana is currently working on multiple wind energy projects, one of which is the Ayitepa wind farm, a project by Upwind Ayitepa Limited. This 225 MW project aims to contribute approximately 600 GW to 700 GW of wind-generated electricity annually to the national grid. The project consists of 75 turbines, each with a maximum height of 150 meters. In addition, the Volta River Authority (VRA) is collaborating with two wind developers to construct 150 MW of wind power across four designated sites in Ghana, namely Anloga, Anyanui, Lekpogunu, and Akplabany, considering the potential of wind resources.

2.15.2 Conventional Energy Sources

Ghana's energy sector is highly dependent on traditional energy sources, which contribute significantly to the country's electricity generation mix. Conventional sources of energy encompass fossil fuels, such as natural gas and crude oil. In 2022, the major sources of energy in Ghana were oil and natural gas, representing 61.8% of the total energy sources (National Energy Statistics, 2023). Thermal power generation, which relies on natural gas as its primary fuel, accounts for 66% of Ghana's installed power-producing capacity. From 2000 to 2008, Ghana had an energy supply of only oil as a fossil fuel due to the unavailability of natural gas during that period. However, in 2009, the supply of natural gas began and has, over the years, experienced a significant increase in its share of the total energy supply, rising from 5.6% in 2010 to 28.2% in 2022.

According to the Energy Commission (2023), a significant oil discovery was made in the Tano Basin, located offshore Cape Three Points in Ghana's Western Region, in 2007, which led to the development of the renowned Jubilee Field, which began production in 2010. Following this, additional fields such as Tweneboah, Enyenra and Ntomme (TEN), and Sankofa-Gye Nyame (SGN) were discovered and developed. Over the past decade, crude oil production has averaged 112,782 barrels per day, resulting in a cumulative total of approximately 453,556,277 barrels. Continuous exploration efforts are ongoing to uncover more oil reserves for the country. Currently, three refineries process crude oil into various petroleum products in Ghana. However, the country relies heavily on the importation of finished products, which accounts for more than 80% of total petroleum product consumption. Petroleum product consumption has increased by a factor of three since the 2000s when it stood at 1,442 ktoe. The transport sector remains the primary consumer of petroleum products.

There has been a general decline in petroleum production; however, products like gasoline and gas oil continued to dominate the list until LPG emerged as a major product in 2021. Kerosene, crude oil, heavy fuel oil (HFO), and aviation turbine kerosene (ATK), among other products, have declined drastically over the years. Similar to this, the government's initiative to increase the use of renewable energy caused a decline in electricity production from thermal plants. As a result, the demand for fossil fuels (natural gas) in the electricity sector has decreased significantly.

Table 2.15.1 Yearly supply of energy from different sources from 2007 to 2022

	Oil		**Natural Gas**		**Hydro**		**Solar**		**Biomass**		**Total**
Year	**ktoe**	**%**	**Ktoe**	**%**	**ktoe**	**%**	**ktoe**	**%**	**Ktoe**	**%**	**ktoe**
2007	3,082	45.3	-	-	320	4.7	-	-	3,408	50.0	**6,810**

2008	2,862	42.5	-	-	533	7.9	-	-	3,344	49.6	**6,739**
2009	2,390	37.8	5	0.1	591	9.4	-	-	3,329	52.7	**6,315**
2010	2,735	39.3	394	5.7	601	8.6	-	-	3,237	46.5	**6,967**
2011	2,898	38.1	796	10.5	650	8.6	-	-	3,256	42.8	**7,600**
2012	3,300	42.1	403	5.1	694	8.9	-	-	3,443	43.9	**7,840**
2013	4,115	46.5	292	3.3	708	8.0	0.3	0.00	3,743	42.3	**8,858**
2014	3,923	43.1	619	6.8	721	7.9	0.3	0.00	3,836	42.2	**9,099**
2015	3,871	40.8	1,185	12.5	503	5.3	0.3	0.00	3,925	41.4	**9,484**
2016	4,466	46.2	692	7.2	478	4.9	2	0.02	4,019	41.6	**9,657**
2017	3,785	39.5	1,146	11.9	483	5.0	2	0.02	4,177	43.5	**9,593**
2018	4,482	41.4	1,684	15.5	517	4.8	3	0.03	4,153	38.3	**10,839**
2019	4,445	39.3	2,117	18.7	624	5.5	4	0.04	4,115	36.4	**11,305**
2020	4,378	36.3	3,014	25.0	627	5.2	5	0.04	4,029	33.4	**12,053**
2021	4,352	37.0	3,189	27.1	647	5.5	11	0.09	3,562	30.3	**11,761**
2022	4,147	33.6	3,472	28.2	704	5.7	14	0.11	3,993	32.4	**12,330**

Source: 2023 Energy Statistics of Ghana

2.15.3 Energy Sources and Greenhouse Gas Emissions Nexus

Greenhouse gas emissions in Ghana are a major concern due to their impact on climate change. The National Greenhouse Gas Inventory (2021) indicated that Ghana's total emissions from all sectors sum up to 59.8 million tons of carbon dioxide equivalent (59.8 $MtCO_2e$) in 2019, which reflects a 16.3% increase relative to 2016 levels and 139.2% for 1990 levels. Over a twenty-nine-year period (from 1990 to 2019), emissions from the energy sector have been steadily rising, primarily due to the use of fossil fuels for transportation and electricity generation, along with population growth and economic growth; this increase is from 2.9 to 27.3 $MtCO_2e$. The transportation sector accounted for the largest share of emissions, with a significant increase in emissions from road transport contributing to this trend, which is primarily due to the rising demand for personal vehicles and freight transportation and the choice of fuel.

Emissions from both conventional and non-conventional sources significantly impact the environment. However, emissions from conventional sources, such as crude oil and natural gas, tend to be higher due to their widespread use in various sectors of the economy (Sharma & Rout, 2017). Emissions production can be viewed as a life cycle process, particularly in petroleum production and consumption, where emissions are released into the atmosphere at every stage of extraction, transportation, refining, and combustion. During extraction, greenhouse gases like methane and carbon dioxide are released into the atmosphere, contributing to global warming. The share of emissions from crude production to the retail tank is about 20% to 30% and about 70% to 80% from the combustion of refined products (S&P Global, 2020). **Figure 2.15.1** shows the life cycle and share of emissions of petroleum fuel.

Natural gas production by Ghana's main gas-producing fields produced about 2.7 million metric tons of oil equivalent in 2021, while crude oil production decreased (Statista, 2023). The emissions arising from both the production and utilisation of fossil fuels constitute a substantial proportion of the nation's total greenhouse gas emissions. Conversely, emissions from non-conventional sources such as hydropower, biomass, wind, and solar power can be classified as indirect, as they do not directly release greenhouse gases during their operational phases. However, the production and disposal of equipment for these sources can still contribute to emissions throughout their life cycle. For instance, there is a marginal emission of methane (CH_4) from the operation of hydropower in the sense that the reservoirs created by dams can lead to the decomposition of organic matter and release methane gas. Additionally, the manufacturing and transportation of solar panels and wind turbines also contribute to greenhouse gas emissions. Biomass in the form of wood fuel and charcoal can also release carbon dioxide when burned, and the felling of forest tree covers for charcoal and wood fuel leads to the destruction of forests, contributing to greenhouse gas emissions.

Although renewable energy sources have lower greenhouse gas emissions compared to fossil fuels, it is imperative to consider the full life cycle emissions associated with their production and operation. However, non-conventional energy sources are what are driving the trends in greenhouse gas emissions, creating a linear nexus where energy sources influence the quantity of emissions and sinks, which then affect the environment.

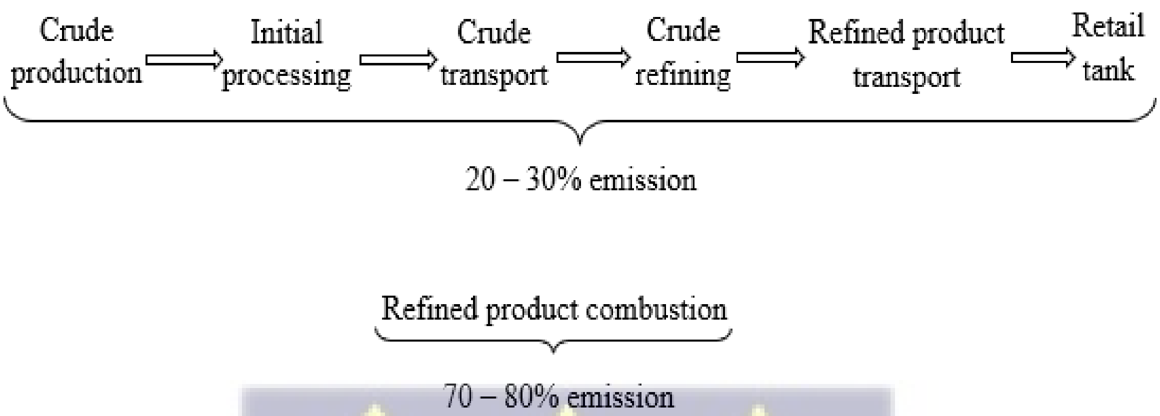

Figure 2.15.1 Life-cycle greenhouse gas emissions of petroleum and the share of emissions

Source: Researcher's construct

2.16 Energy Policies in Ghana: Historical Evolution and Current Status

Several policies and initiatives to ensure energy security, access, and sustainability have shaped Ghana's energy sector. The country's energy policy landscape has evolved significantly, reflecting changing global trends, technological advancements, and shifting priorities. For example, the Renewable Energy Act of 2011 was a key milestone in promoting renewable energy sources in Ghana's Energy Commission has been instrumental in regulating and supervising the energy sector to promote efficiency and sustainability. This has led to the development of various policies and frameworks, such as the Energy Commission's Act of 1997 (Act 541) and the initial National Strategic Energy Plan (SNEP I) in 2006. The country's overreliance on hydropower for electricity, which failed owing to insufficient rainfall in the Volta reservoir's catchment areas, limited the country's energy supply during the 1997–1998 power crisis, which gave rise to this plan (SNEP I, 2006). The plan laid the foundation for Ghana's energy sector by emphasising the importance of energy security, diversification of energy sources, and promoting private sector participation. Similarly, the plan outlined specific targets for increasing energy generation capacity, reducing reliance on hydropower, and promoting renewable energy sources such as solar and wind. It also focused on improving energy efficiency and establishing a regulatory framework to attract private investment in the energy sector.

In the early years of Ghana's energy sector (1950s–1980s), the sector was initially dominated by state-owned enterprises, with a focus on hydroelectric power generation. The country's first energy policy, the 1957 Energy Policy, emphasised the development of hydroelectric power and the creation of a state-owned energy company, the Volta River Authority (VRA). The policy laid the foundation for future energy policies that would prioritise sustainable energy development and diversification. According to Edjekumhene et al. (2001), in the 1980s and 1990s, the energy sector underwent significant reforms during the Structural Adjustment Program (SAP) era. The SAP aimed to liberalise the energy sector, privatise state-owned enterprises, and increase private sector participation. This period saw the introduction of the 1995 Power Sector Reform Policy, which aimed to create a competitive electricity market and increase private sector participation.

In the wake of SAP, Ghana's energy sector has continued to progress, with a focus on enhancing access to electricity, promoting energy efficiency, and advancing renewable energy. Key post-SAP policies include the renewable energy policy, the Renewable Energy Master Plan, the National Energy Strategy, the Energy Sector Strategy and Development Plan (ESSDP), and the periodically updated national energy policy. For example, the 2010 National Energy Policy delineated the Government of Ghana's policy orientation toward the prevailing challenges in the energy sector. To facilitate an understanding of Ghana's energy policy framework, the document provided a concise overview of the government's policy direction. It addressed a wide array of challenges and issues concerning electricity, petroleum, renewable energy, waste-to-energy, energy efficiency and conservation, energy and the environment, energy and women, and the future management of the sector. It also underlined the necessity of developing renewable energy sources, expanding private sector involvement, and maintaining a diverse energy mix. The promotion of renewable energy sources enhanced private sector involvement, and an emphasis on sustainable energy development defines Ghana's present energy policy environment.

Currently in effect are the 2019 Electricity Supply and Distribution Policy, the 2019 Renewable Energy Master Plan (REMP), and the 2021 National Energy Policy. The government's objectives for the energy sector are outlined in the 2021 National Energy Policy, which aligns with the 2010 National Energy Policy. It emphasises the importance of a diversified energy mix, increased private sector involvement, and the expansion of renewable energy sources. The strategy aims to enhance energy efficiency, reduce greenhouse gas emissions, and ensure a reliable and secure supply of high-quality energy services. The 2019 Renewable Energy Master Plan (REMP) shares similar goals and aims to raise the proportion of renewable energy in Ghana's energy mix to 10% by 2030. The plan underscores the advancement of energy storage and efficiency, as well as the development of solar, wind, and hydroelectric power. Enhancing the effectiveness and dependability of energy supply and distribution is another goal of the 2019 Energy Supply and Distribution Policy. The program places a strong emphasis on the creation of renewable energy sources, enhanced private sector involvement, and a competitive electricity market.

2.16.1 Renewable Energy (RE) and Non-Renewable Energy (Non-RE) Policies

Ghana's reliance on non-renewable energy sources and its associated consumption has garnered greater attention due to the limited supply and detrimental impact on the environment. With the escalating demand for renewable energy sources such as solar and wind power, coupled with the numerous benefits of widespread deployment of renewable energy, the demand for non-renewable energy has shown a recent decline. Renewable energy policies, both national and international, have impacted Ghana's production and consumption of non-renewable energy in one way or another. The difficulties in implementing a low-carbon economy have made it necessary to develop policies and programs on the production and consumption of non-renewable energy resources. The Paris Agreement, the Sustainable Development Goals, and other international and local policies that are climate-related primarily direct Ghana's use of non-renewable energy.

The importance of promoting sustainable development and reducing greenhouse gas emissions is explicitly emphasised in Article 6 of the Paris Agreement, leading to the implementation of emission trading programs and carbon pricing. The European Union Emission Trading System (EU ETS) has notably influenced Ghana's non-RE deployment and clean energy transition policies, prompting the nation to prioritise renewable energy sources and decrease its carbon footprint.

Concurrently, renewable energy (RE) has become a focal point in Ghana in recent years, with the government establishing ambitious targets for its increased utilisation. These targets are shaped by policies and initiatives aimed at fostering the development of renewable energy sources and reducing the country's dependence on fossil fuels. The current renewable energy policy landscape in Ghana is characterised by its focus on sustainable energy development and the promotion of renewable energy sources. A significant milestone was the introduction of the Renewable Energy Act in 2011 (Act 832), which provided the legal foundation for the establishment of support programs, such as Feed-in Tariffs (FiTs) and net metering, for the deployment of renewable energy sources. This Act evolved as a result of the government's commitment to increasing the proportion of renewable energy in the country's total energy mix due to its excessive reliance on fossil fuels, inadequate energy supply, and limited access to electricity. Additionally, the Act outlines the responsibilities of various governmental bodies in implementing policies and regulations to foster the development of renewable energy sources.

In alignment with these efforts, the National Energy Policy (2010) prioritised the development of new energy technologies and improving rural access to electricity through the use of renewable energy sources, while also emphasising renewable energy deployment, waste-to-energy management, and energy efficiency. By providing adequate financial resources, the program aimed to reduce greenhouse gas emissions and promote the development of sustainable energy, ultimately leading to the production of more efficient and environmentally friendly energy. The inclusion of renewable energy in Ghana's energy mix was reaffirmed in the 2021 National Energy Policy, reflecting the country's aggressive goals to increase the proportion of renewable energy sources in its energy mix by 2030.

Furthermore, the Renewable Energy Master Plan (REMP), developed with support from the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF), serves as an investment-focused framework for the promotion and development of renewable energy resources in Ghana. The REMP's vision aims to harness renewable energy resources sustainably and position Ghana as a country with expertise in renewable energy technology. The strategy sets specific targets to be achieved by 2030, including increasing the proportion of renewable energy in the national energy generation mix, reducing reliance on biomass as the primary fuel for thermal energy applications, providing renewable energy-based decentralised electrification options in off-grid communities, and promoting local content and participation in the renewable energy industry. The REMP also outlines comprehensive plans and initiatives for the advancement of various renewable energy technologies, such as solar, wind, biomass, and hydropower. It also covers legislative and regulatory frameworks, finance, capacity building, grid integration, and provisions for the creation of committees and units to oversee the plan's daily execution.

In addition, the government has put in place programs like the rooftop solar program and feed-in tariffs to encourage investment in renewable energy projects and to encourage the use of solar energy by homes and businesses. In addition to lowering the nation's carbon footprint, these initiatives hope to improve energy security and accessibility for all Ghanaians while also generating new employment possibilities in the renewable energy industry.

2.16.2 Energy Efficiency (EE) Policies

Ghana's households and companies face power supply instability and inadequate energy supply, which are regarded as major barriers to the nation's economic progress. This is especially true for sectors like manufacturing, where a steady supply of energy is essential to competitiveness and productivity. Businesses must rely on pricey alternative energy sources to run at full capacity in the absence of a steady energy supply. Energy efficiency (EE) initiatives, such as the adoption of energy-saving technologies across all industries, can, nevertheless, lessen this threat. This will lower operating costs as well as the carbon footprint of companies and other industries that depend on energy for day-to-day operations. To support sustainable development and fight climate change, the Ghanaian government has put in place EE policies and initiatives.

The Ministry of Energy and the Energy Commission of Ghana have been working together to enforce laws and programs in order to ensure compliance and progress towards a more sustainable future. This collaboration includes the monitoring and enforcement of regulations such as the Renewable Energy Act and the Energy Efficiency Standards and Labelling Program. Additionally, various policies and initiatives, such as the National Energy Policy, the Energy Efficiency (EE) policy measure for cooling appliances, the Energy Conservation Building Code, the Drive Electric program, and the policy prohibiting the importation of used electrical appliances, have been implemented to support energy efficiency and conservation.

The National Energy Policies of 2010 and 2021 emphasised the importance of energy-saving and energy-efficient initiatives and outlined measures and frameworks for energy efficiency. The goal of these policies is to overcome barriers hindering the adoption and advancement of energy-saving initiatives. Fiscal incentives, raising public awareness, developing institutional and human resource capacity, and financial intermediation were also highlighted as necessary policy actions to support energy efficiency and conservation.

The Renewable Energy Master Plan of 2019 underscores the significance of energy efficiency in renewable energy interventions and advocates for the adoption of energy conservation practices and the promotion of energy-efficient technology to enhance energy efficiency. The plan also outlines the implementation of standards and labelling schemes for lighting devices, air conditioners, and refrigerators to promote energy efficiency.

Furthermore, the government has introduced aggressive and sustainable energy efficiency programs and strategies to promote the use of energy-efficient appliances and raise public awareness of energy conservation and management in both industrial and residential sectors. These initiatives include the promotion of energy-efficient lighting and appliances, rebate programs for replacing outdated refrigerators with new, energy-efficient models, and the replacement of incandescent lightbulbs with compact fluorescent lights.

The initiative for electric vehicles (EVs) aims to mitigate climate change, reduce pollution, and address the overcapacity of electricity generation in the short to medium term. This initiative seeks to drive demand and utilisation of electricity and promote the use of electric vehicles as an alternative mode of transportation in Ghana. The government also aims to have at least one hundred electric vehicles and ten public charging outlets in the country by 2020.

Various programs and policies aimed at promoting energy efficiency have played a significant role in ensuring a sufficient energy supply in the nation. The ban on the importation of used electrical items, deployment of energy-efficient lighting and appliances, and the provision of tax incentives and financial support for businesses investing in energy-efficient technologies through the Sustainable Use of Natural Resources and Energy Finance (SUNREF) program have contributed to the increased energy efficiency in the country.

CHAPTER 3 (THREE)

METHODOLOGY

3.0 Introduction

This chapter provides an overview of the methodology utilised in this research and presents a comprehensive account of the research design, data collection, and analysis techniques, as well as the tools and methodologies employed to accomplish the study's objectives. Additionally, the study employs a purely quantitative research design, leveraging the capabilities of the Low Emission Analysis Platform (LEAP) to conduct long-term energy demand, supply, and emissions forecasting for Ghana from 2010 to 2050.

3.1 Study Area

The study area is Ghana, chosen due to its strategic importance in West Africa, its evolving energy landscape, and the urgent need for sustainable energy planning amid growing demand and climate change concerns (Energy Commission, 2023). The geographic scope encompasses the entire country, with sectoral disaggregation to capture regional variations and sector-specific dynamics.

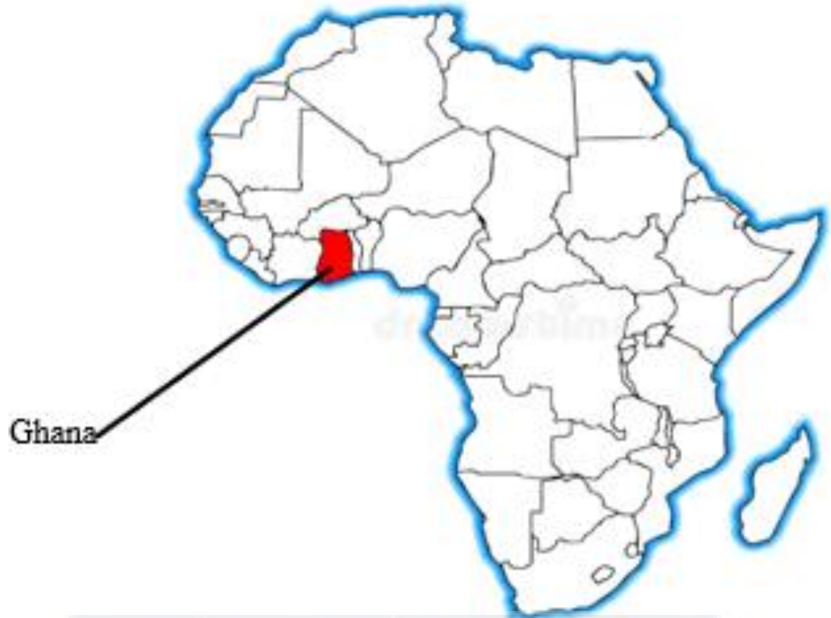

Figure 3.1.1 The map of Africa showing Ghana

Source: Dreamstime.com

3.2 Justification of the method

The methodology selected for this study is well-suited for the research objectives and the nature of the problem under investigation. The primary rationale behind choosing the LEAP (Low Emission Analysis Platform) model as the core methodology is its applicability to long-term energy planning and policy analysis, which closely aligns with the goals of this study. The LEAP model facilitates comprehensive modelling of energy demand, transformation, and supply across all sectors of the economy, which is in line with the forecast of Ghana's long-term energy supply and demand. Its scenario-based structure allows for the exploration of various energy futures based on different assumptions about policies, technologies, economic growth, and other key drivers, which is essential for evaluating the long-term implications of different energy strategies for Ghana. The LEAP model's flexibility in data structures and modelling approaches allows for tailored analysis to the specific needs of the study. Furthermore, its user-friendly interface and well-documented features make it accessible to researchers and policymakers. The LEAP model is particularly well-suited for energy planning in developing countries like Ghana, where data availability and quality can be challenging. Its low initial data requirements and ability to handle uncertainty make it a suitable choice for this context. Moreover, the use of the LEAP model in previous studies on Ghana's energy sector, including the Ghana Integrated Power Sector Master Plan, ensures that the findings of this study will be comparable and relevant to the existing body of knowledge on Ghana's energy system.

This study will utilise exclusively a quantitative approach in addition to the LEAP model. This approach is well-suited for the research objectives, as it allows for a comprehensive understanding of the problem and the development of robust policy recommendations. The quantitative component, focused on the LEAP model, will provide numerical forecasts of Ghana's energy supply and demand using historical data and various scenarios, forming the core of the analysis and providing vital insights for policymaking. Moreover, the study will verify the accuracy of the LEAP model's projections by comparing them with real data on energy supply, demand, and emissions. This validation process is designed to ensure the dependability of the study's conclusions and the credibility of the policy suggestions.

3.3 The Low Emission Analysis Platform (LEAP)

The Stockholm Environment Institute has developed LEAP, a powerful software tool for analysing energy policies and assessing climate change mitigation strategies. This tool has gained widespread adoption across government agencies, academic institutions, non-governmental organisations, consulting firms, and energy utilities in more than 190 countries. LEAP has become the preferred choice for countries engaging in integrated resource planning, greenhouse gas mitigation assessments, and the development of Low Emission Development Strategies (LEDS), particularly in the developing world. Notably, at least 32 countries have utilised LEAP to create energy and emissions scenarios that formed the basis for their contributions to global climate change action.

LEAP operates at two fundamental levels: built-in calculations handle straightforward energy, emissions, and cost-benefit assessments, while spreadsheet-like expressions enable users to specify time-varying data and construct complex multi-variable models. The latest versions of LEAP also feature optimisation modelling capabilities, allowing the development of least-cost models for expanding and dispatching electric system capacity under various constraints.

This software is designed for scenario analysis, empowering policy analysts to create and compare alternative scenarios in terms of energy requirements, social costs, benefits, and environmental impacts. Its flexible and transparent data structures are ideal for an iterative analytical approach, where users can introduce complexity based on available data and gain deeper insights into the questions being addressed in the analysis.

LEAP boasts an intuitive reporting interface, enabling users to visualise, interpret, and identify errors in the results. It generates a wide array of results that can be presented as charts, tables, and maps, with the option to export the data with a single click. Additionally, LEAP can produce results in the form of standard energy balance reports, which can be displayed in various formats.

3.4 Data Collection Process

Data was gathered from secondary sources, ensuring comprehensive coverage of socio-economic, demographic, and energy-related variables. These sources include the Ghana Statistical Services

(GSS), the Energy Commission of Ghana, the International Energy Agency (IEA), and the World Bank (Ghana Statistical Service, 2022; IEA, 2024; World Bank, 2024). The dataset covers:

- Population size, urban/rural split, age distribution, fertility rates, and urbanisation trends (GSS, 2022; Quartey, 2023a).
- Historical energy supply and demand data segmented by energy source, sector, and fuel type (Energy Commission, 2023; Statista, 2024).
- Capacity and efficiency of existing power plants, renewable energy potentials, and transmission infrastructure (Ghana Energy Outlook, 2023; Atuahene, 2022).

Interpolation and extrapolation techniques were applied where data gaps existed to ensure consistency across years (Ridder, 2014; Ahmad & Ahmad, 2019). This approach enhances the reliability of input data for model calibration, using the standard formula:

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \tag{1}$$

Where,

y = the available value for which x will be obtained (i.e. y = the year 2010)

y_1 and y_2 are available values (for this study, the y values correspond to Years)

x = the value to be obtained for the given y value

x_1 and x_2 are the available values for the corresponding y_1 and y_2 values respectively

Similarly, equation 1 was used where there was a need for extrapolation.

3.5 The LEAP Process

3.5.1 Model Calibration and Validation

The LEAP model was calibrated using historical energy consumption and supply data from 2010 to 2022, ensuring that the model outputs align with observed trends. Calibration involved adjusting end-use efficiencies, technological coefficients, and resource availabilities until simulated outputs closely matched historical records. To strengthen the robustness of the model, multiple validation techniques were employed:

1. **Historical Reproduction**: Comparing model outputs with actual historical data to assess accuracy.

2. **Benchmarking**: Comparing results with findings from other similar studies in sub-Saharan Africa, such as those by Nyasapoh et al. (2022b) and Foday et al. (2023), to ensure consistency within regional contexts.

The process involved the use of different interfaces within the LEAP application. **Figure 3.4.1** provides a diagram representing the process involved in the LEAP analysis.

Figure 3.5.1 The processes involved in the LEAP analysis
Source: Researcher's generation

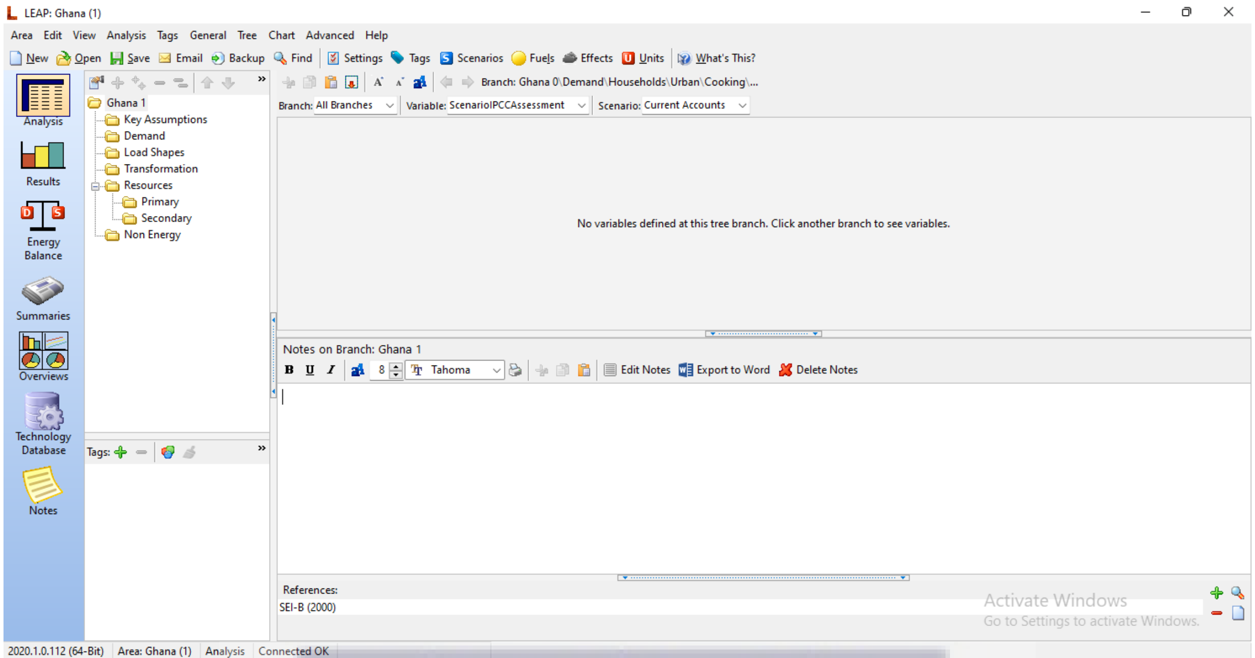

Figure 3.5.2 The introductory interface of LEAP
Source: Researcher's generation

Figure 3.5.2 presents the main and start-up screen. On the main screen are major views on the left side of the screen: analysis, results, energy balance, summaries, overviews, technology database and notes.

The analysis view presents an area where data is entered or viewed to construct models and scenarios. This view has two panes: at the top is a table in which data can be edited or viewed as well as the creation of modelling relationships. The area below the top pane contains charts and tables that summarise the data entered. The analysis view comes with a main part called the "tree" with branches where sub-trees can be built for data input purposes. The main branch of the tree is the area being considered; for this study, the area is named Ghana. Under the branch Ghana are other branches, namely: key assumptions, demand, load shape, transformation, resources (with sub-branches as primary and secondary) and non-energy.

The Results View presents an area where the outcomes of the various scenarios are calculated and examined, and can be viewed as graphs and tables. Similarly, the Energy Balance View presents energy results calculated in LEAP as specially formatted energy balances and Sankey diagrams.

3.6 Data Analysis

The LEAP model's scenario module was employed to project energy supply, demand, and greenhouse gas emissions. This involved:

- Defining sectoral activity levels based on historical trends and forecasted socio-economic variables.
- Specifying technological efficiencies, fuel shares, and resource potentials informed by the extracted data.
- Running the model iteratively to generate projections up to 2050, with annual timestep granularity.

Visualizations, tables, and key indicators such as total energy consumption, capacity expansion, emissions, and energy security metrics (e.g., reserve margins, energy surplus/deficit) were generated for comparative analysis.

3.7 Addressing Model Limitations

The study acknowledges inherent limitations of LEAP, including its reliance on static efficiencies and assumptions, potential data inaccuracies, and limited capacity to account for complex socio-political dynamics. To mitigate these, the study:

- Benchmarked model outcomes against regional and international studies.

- Cross-checked data inputs with multiple sources for consistency.
- Documented assumptions transparently in the model report.

3.8 Ethical Considerations

This study relies solely on secondary data, and all sources are publicly available or licensed. Data handling complies with research ethics standards, ensuring transparency and replicability.

3.9 Scenario Modelling Process

2010 was used as the base year for the study. This is because the Ghana Statistical Services conducted the national population and housing census in 2010, hence providing data on demographics. Similarly, 2010 was a stable year for energy production and supply in Ghana, where one of the major policies on energy (i.e. the 2010 National Energy Policy) was adopted, and other surveys were conducted with reports written and published, hence the availability of data needed for this study.

3.9.1 Scenario Development

Two primary scenarios were constructed:

3.9.1.1 Business-As-Usual (BAU)

The BAU scenario reflects current policies, demographic trends, and technological trajectories.

Key Assumptions

Continuation of Current Energy Policies and Practices

The BAU scenario assumes no major policy reforms or new energy initiatives beyond those already adopted by 2023, reflecting a "status quo" trajectory. Existing subsidies, tariffs, and regulatory frameworks remain largely unchanged. This aligns with observed inertia within Ghana's energy sector and provides realism grounded in the present policy landscape (Energy Commission, 2023; Ministry of Energy, 2023).

Socioeconomic Drivers

The population is projected to grow at an annual rate of approximately 2.1%, with steady urbanisation following historical trends (Ghana Statistical Service, 2022).

GDP growth is incorporated based on medium-term government forecasts, without additional accelerated industrialisation or structural changes (Ministry of Finance, 2023).

Energy Demand Growth Rates

Energy demand increases at historical average rates in all sectors, households, transport, industry, and commerce, with no enforced efficiency improvements or technology shifts beyond minor, market-driven changes. For example, traditional biomass continues to dominate cooking energy use in rural households (Energy Commission, 2023).

Technology Deployment and Fuel Mix

The generation and consumption technology mix is assumed to evolve slowly, primarily reflecting the replacement of ageing capacity without rapid adoption of renewables or low-carbon technologies beyond current levels. Fossil fuels retain dominant shares in power generation and transport fuel use, consistent with recent fuel consumption data (Energy Commission, 2023; IEA, 2024).

Energy Access and Infrastructure

The scenario assumes incremental growth in electricity access based on current grid expansion plans, but does not include accelerated rural electrification or adoption of clean cooking solutions at scale. Distribution losses and grid reliability challenges persist (Ghana Energy Commission, 2023).

Emissions Trajectory

Without targeted mitigation, greenhouse gas emissions continue rising, driven by increasing fossil fuel consumption and sectoral energy demand growth. No carbon pricing or subsidy reforms are assumed, leaving emissions unmanaged at the policy level (Ghana Ministry of Environment, 2024).

3.9.1.2 Mitigation and Policy (MIT)

The MIT incorporates policy interventions such as increased renewable energy penetration (targeting 30% by 2030 and 50% by 2050), energy efficiency measures across sectors, and expansion of low-carbon technologies, aligned with Ghana's NDC commitments (Ghana Energy Outlook, 2023; Ghana NDC, 2021).

Key Assumptions

Renewable Energy Targets

Renewable energy share is modelled to increase progressively, reaching 30% of the energy mix by 2030 and 50% by 2050, reflecting Ghana's stated goals for diversified and sustainable energy sources (Energy Commission, 2023; NETF, 2023). Solar, wind, biomass, and small hydro are the main contributors to this growth, with capacity additions constrained by resource availability and infrastructure development plans.

Energy Efficiency Measures

Assumptions include phased implementation of appliance and equipment efficiency standards across sectors. For example, improved cookstoves in rural households, efficient lighting and refrigeration in urban homes, and optimised industrial processes reduce energy intensity. These measures are based on Ghana's Energy Efficiency Policy and global best practices (GhEEA, 2021; IEA, 2023).

Transport Sector Transformation

The scenario includes the gradual adoption of electric vehicles and expanded public transport infrastructure, lowering fuel consumption and emissions in the transport sector. Penetration rates are modelled in alignment with electric mobility strategies and expected infrastructure readiness timelines (Transport Ministry of Ghana, 2023).

Carbon Pricing and Subsidy Reform

Modest carbon pricing is introduced progressively to internalise environmental costs and incentivise cleaner energy choices, accompanied by gradual reform of fossil fuel subsidies, which currently distort market signals and hinder renewables uptake [Ghana Ministry of Finance, 2023].

Technological Deployment Constraints

Realistic limitations on the pace of deployment of new technologies are included, recognising financial, institutional, and infrastructural barriers. Growth rates of renewables and low-carbon technologies are capped annually to reflect historical trends and expected market absorptivity.

The steps in the scenario modelling process are as follows:

Step 1: Branch Creation

In the analysis view, the four main sectors considered in this study were created as sub-branches under the demand branch, namely: household, industry, transport, and commercial. The household sector was classified into rural and urban households, and the rural households were further classified as electrified and non-electrified households. Various energy-related activities were created as sub-branches under the various classified households. The identified activities that require energy use are cooking, lighting, refrigeration, and others (others include other energy-using devices such as irons, fans, air conditioners, etc.). The identified activities were associated with different energy technologies and fuels utilised; for instance, the technologies used by urban households for cooking are LPG stoves, electric stoves, kerosene stoves, charcoal stoves, and wood stoves. The respective fuels are LPG, electricity, kerosene, charcoal, and wood. **Figure 3.9.1** presents the tree for the demand of households.

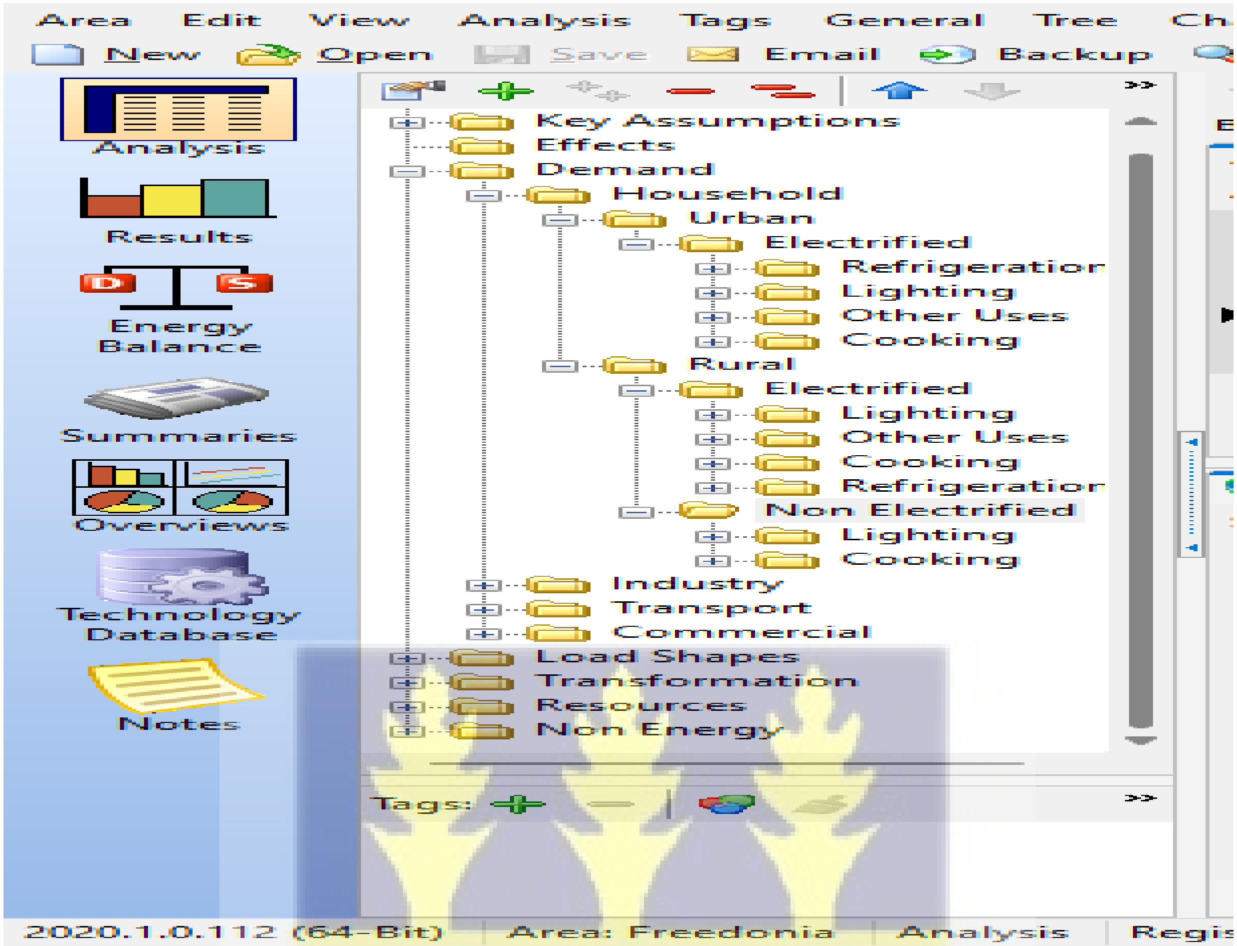

Figure 3.9.1: The tree branches utilised for the study
Source: Researcher's generation

Step 2: Base year data input (household sector)

The data collected on households for the base year were entered into the system under current accounts. **Figure 3.9.1 and Figure 3.9.2** present the data input process for the two households and that of the urban households respectively.

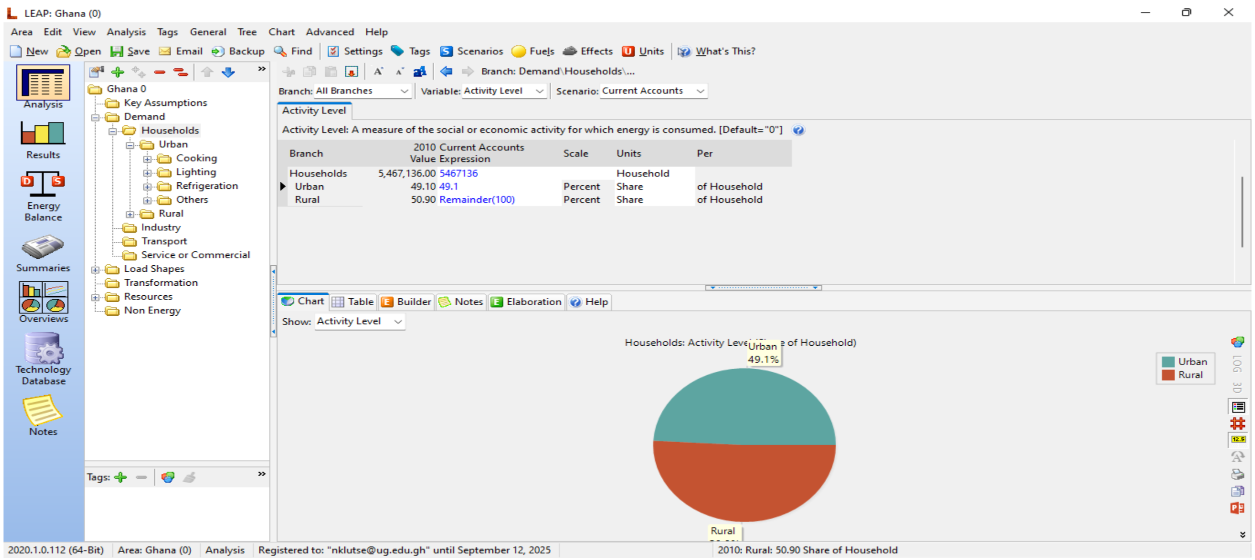

Figure 3.9.2: Data analysis process of the household sector (urban and rural)
Source: Researcher's generation

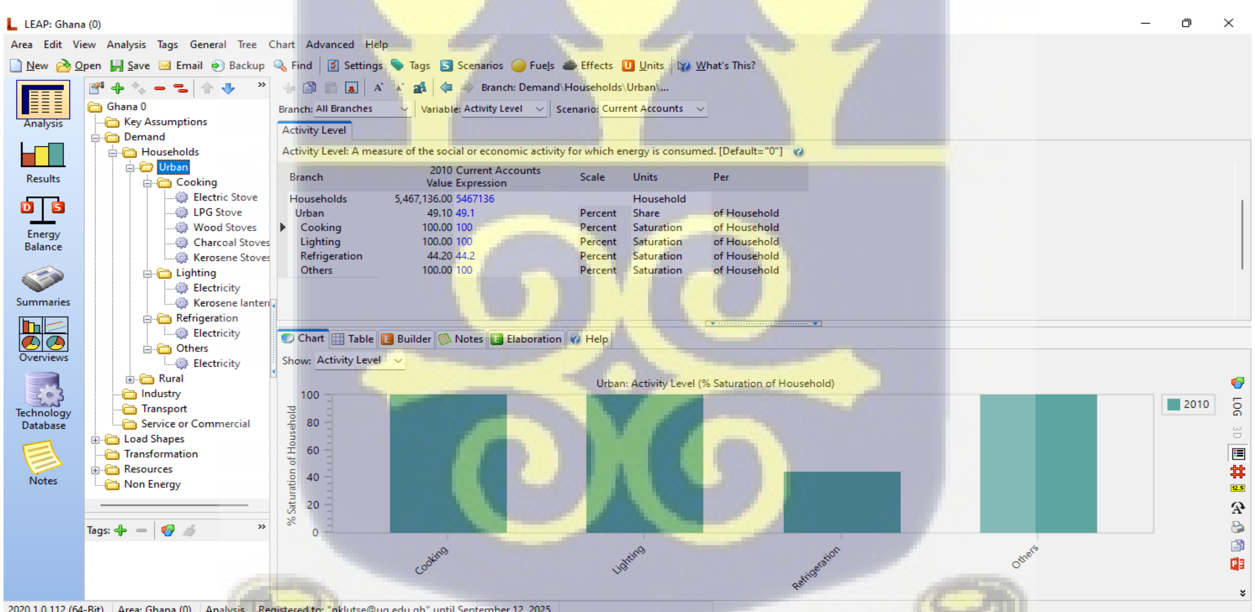

Figure 3.9.3: Creation of tree branches for the different activities in the sectors
Source: Researcher's generation

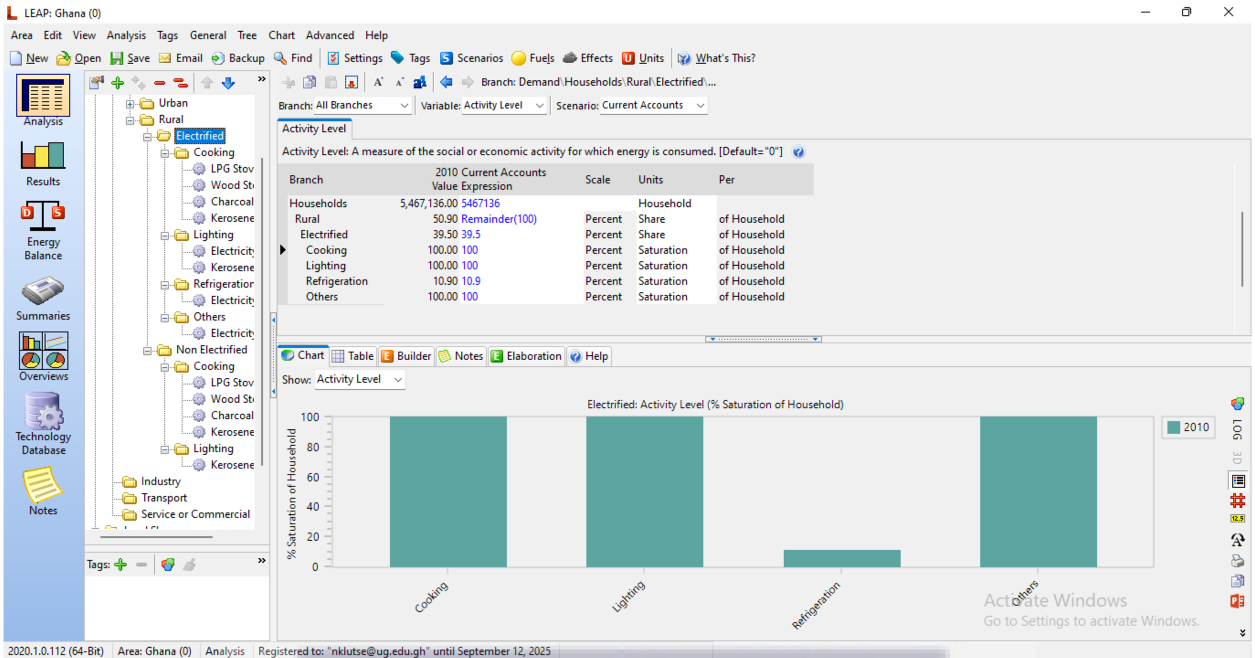

Figure 3.9.4: The process involved in analysing data for each activity in both rural and urban households
Source: Researcher's generation

Step 3: Viewing base year results (household sector)

The result view tab is selected, and the results of the input data are calculated, which is then viewed in the form of graphs and tables. **Figures 3.9.4 and 3.9.5** demonstrate the tabular and graphical presentation of the results, respectively.

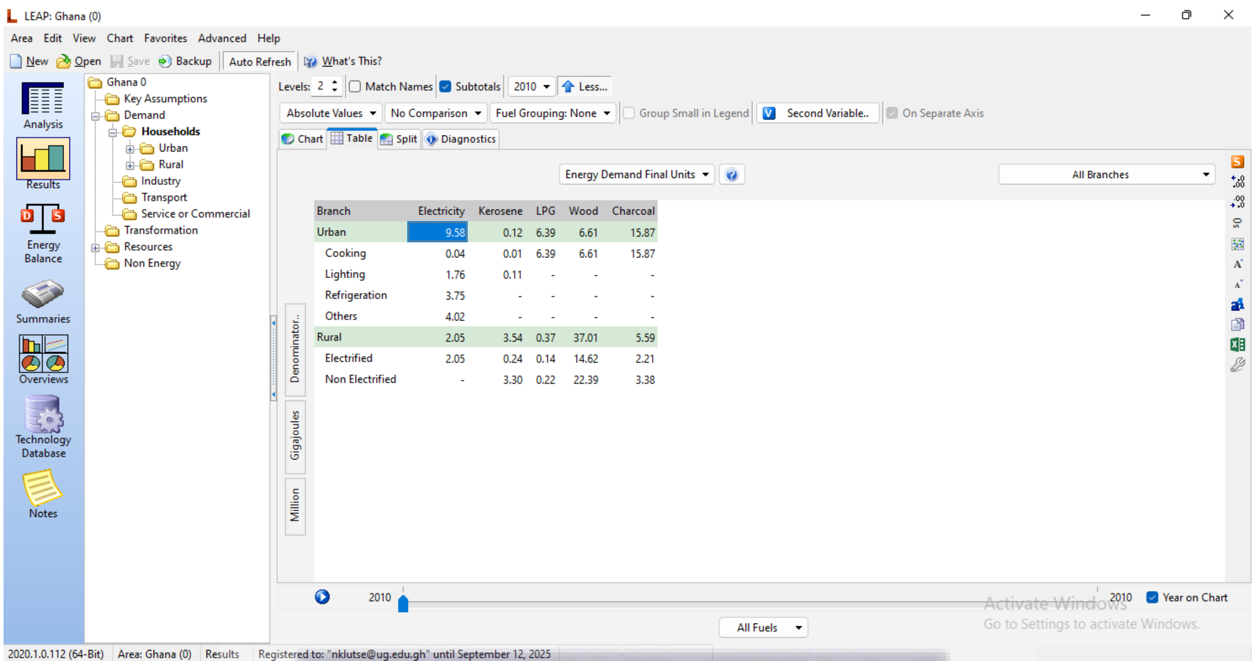

Figure 3.9.5: The process involved in the result viewing of the data analysed
Source: Researcher's generation

Step 4: The baseline scenario data input

The account was switched from the "current account" to "baseline" where data input was made for the baseline scenario, and results were obtained for years from 2010 to 2050.

Steps 1 to 3 are repeated for the other sectors (industry, transport, and service).

Step 5: Transformation Analysis

Data input was done for electricity generation and charcoal production in Ghana. The data used for the electricity generation focused on transmission and distribution losses. With a reserve margin of 11.6%, the analysis was conducted for the two major feedstocks (hydro and natural gas) for electricity generation in Ghana, where there was a focus on the capacities of the plants as well as their historical production, efficiency and availability. In the baseline scenario, it was recorded that there is an expected addition to the generation mix from different sources such as additional hydro, thermal and other renewables (solar, wind, wave, biomass, etc.). The data obtained were analysed, and results were obtained.

Step 6: Mitigation and greenhouse gas emission analysis

The various policies towards greenhouse gas mitigation and policy measures for the energy sector were considered, and projections for energy demand were conducted based on some assumptions, such as the growth rate of demand in the four main sectors (household, industry, transport and commerce). The emissions from these sectors were obtained for both the baseline scenarios and the policy intervention scenarios, and the emissions were further categorised into three major greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The mitigation and policy measures that were considered are;

1. Energy efficiency measures for lighting and refrigeration.
2. 30% renewable energy penetration in the energy mix by 2030.
3. Electric vehicle initiative (EVI).
4. Clean cooking technologies.
5. Green building codes.

CHAPTER 4 (FOUR)

DATA ANALYSIS AND RESULTS

4.0 Introduction

The data used for this analysis are sourced from reports by the Energy Commission of Ghana and Ghana Statistical Services (GSS), including the Energy Statistics Reports, Energy Outlook Reports, Ghana Living Standard Survey Reports, and Population and Housing Census Reports, as well as data from the World Bank, International Energy Agency (IEA), and Statista. The section begins with an analysis of the collected data and presents the results of the quantitative analysis, including projections of energy demand and supply under different scenarios. The findings of the data analysis conducted using the Low Emission Analysis Platform (LEAP) to forecast Ghana's long-term energy supply and demand are outlined. Subsequently, the results are discussed within the context of Ghana's energy sector, highlighting the key findings and their implications for energy policy and strategic planning. The quantitative analysis was executed using the LEAP model, which was fine-tuned using historical data on energy supply and demand, alongside socio-economic data such as population growth, economic growth, and industrial progress. The model was then leveraged to forecast future patterns grounded on assorted assumptions about forthcoming energy policies and technological advancements.

The quantitative analysis results are presented through tables, figures, and charts, providing insights into energy demand and supply forecasts under different scenarios. These scenarios include business-as-usual, low-carbon, and specific energy policy-based scenarios.

4.1 Data Analysis

According to the Ghana Statistical Services, in the base year (2010), the population of Ghana is 24,658,823 (51.24% female and 48.76% male) living in 5,467,136 households. Of these households, 12545229 (50.9%) are urban and 12113594 (49.1%) are rural with an annual average intercensal growth rate of 2.5%. The energy consumption per capita in 2010 was 2142kWh.

For this study, four different sectors were considered: the residential sector, industry, transport, and commercial buildings.

4.1.1 Current Accounts Analysis

4.1.1.1 Household Sector

4.1.1.1.1 Urban Household

83.8% of urban households have access to electricity, and 0.76% of these households (tertiary institutions inclusive) use electric stoves for cooking, 28.9% use natural gas stoves, and the remainder use biomass (wood and charcoal). 47.5%, 16.1% and 0.6% of urban households use charcoal, wood, and kerosene as cooking fuel, respectively. Assume that each household uses only one type of cooking device. The annual energy intensity for electric stoves is 600 kWh per household, while for natural gas stoves it is 174 kg per household. In urban areas, 84.3% of households use electricity for lighting, with an average energy intensity of 261.6 kWh. Additionally, 44.2% of urban households have refrigerators, which consume an average of 877.2 kWh per year. Other devices, such as computers, televisions, and fans, collectively consume 416.4 kWh per urban household annually.

4.1.1.1.2 Rural Households

The rural households are divided into electrified and non-electrified categories. According to data from the World Bank, 39.5% of rural households have access to electricity. Among the electrified rural households, 10.9% own a refrigerator, which typically consumes 1,227.6 kWh per year. Additionally, all electrified rural households use electricity for lighting, with an average consumption of 261.6 kWh per household. Of these households, 33.6% also utilize kerosene lamps for additional lighting, with an average annual consumption of 18 litres per household. Other electric devices such as TVs, radios, fans, and irons contribute to an average consumption of 356.4 kWh per household per year. On the other hand, non-electrified households rely solely on kerosene lamps for lighting, with an average consumption of 54 litres per household per year.

Table 4.1.1 Share of fuel, type of technology and energy intensity for cooking in rural households

Cooking Technology	Type of fuel	Households (%)	Annual Energy Intensity
Charcoal Stove	Charcoal	15.8	440 kg
Wood Stove	Wood	77.1	1113 kg
LPG Stove	LPG	4.8	58 kg
Kerosene Stove	Kerosene	0.1	8.7 litres

Source: National Energy Statistics (2017) and Ghana Living Standards Survey (1992, 1999, 2006, 2013, 2017).

4.1.1.2 Industry Sector

Manufacturing is the principal energy-intensive industry in Ghana. All other industries are grouped into one category. The manufacturing sub-sectors include cement production, aluminium production, steel and iron production, and other industries.

Table 4.1.2 Output of subsectors for the manufacturing industry

Subsectors	Output (Million) tonnes				
	2010	2012	2015	2017	2020
Aluminium	N/A		0.034	0.041	0.038
Steel and iron	1				0.24
Cement	3.5	5		6.54	7
Other Industry	6.15 USD				

Source: Energy Commission, IEA & Statista

Energy use in the iron and steel as well as aluminium industries is categorised into two types: process heat and motive power. On average, the production of one tonne of aluminium requires 15.0 MWh of electricity, while one tonne of steel and iron requires 4 MWh. In addition, the production of one tonne of cement requires approximately 0.11 MWh of electricity. In 2010, Ghana's other industries consumed a total of 16.58 million gigajoules (GJ) of energy, with 60% of this energy being in the form of electricity and the rest from other fuels.

Table 4.1.3 Fuel share of production

Fuel type	% of fuel used
Diesel	54.2
Residual Fuel Oil (RFO)	5.6
LPG	0.9
Wood	38.6
Charcoal	0.7

Source: Energy Commission (2023)

4.1.1.3 Transport Sector

The transport sector is categorised into freight transport and passenger transport for this study. Each category has been further classified into modes of transport: road transport, rail transport and air transport.

Passenger transportation in Ghana primarily occurs via road (cars and buses), rail, and air. Although no data on kilometres travelled was available in 2010, surveys suggest that cars typically carry an average of 3.0 occupants, while buses have an average of 20 passengers. Surveys also indicate that the current fleet of cars achieves a fuel economy of approximately 12 km per litre of gasoline, while buses travel about 14.7 km per litre of diesel. In 2010, trains covered a total of 7 million passenger-kilometres, with all rail transport being diesel-powered. Additionally, the average freight transportation per capita is 0.3 tonne-km, with 90% of freight being transported by road and the remaining 10% by rail. Road transport utilises an average of 4 MJ of diesel fuel per tonne-km, while diesel freight trains have an energy intensity of 3 MJ per tonne-km..

4.1.1.4 Services or Commercial Sector

About 0.1% of the total area of Ghana was occupied by commercial spaces in the base year. Energy consumption in the service sector is dominantly lighting and cooling where 3MW and 8MW of electricity is used per year. The spaces use both solar (daylight), wind (ventilation) and electricity (solar and wind are regarded as non-energy) for lighting (20% and 80% share for solar and electricity of total the lighting energy respectively) and cooling (10% and 90% saturation of wind and electricity of the total cooling energy respectively). Electricity for cooling has an efficiency of 100%, while the efficiency of wind is 25% and solar is 40%.

4.1.2 Baseline Scenario

4.1.2.1 Key Assumptions (Household Sector)

The total number of households will increase in 2050 with an annual growth rate of 2.04%. According to the Ghana Statistical Services, it is projected that by 2050, 50.9% of households in Ghana will be located in urban areas, a reverse situation for the base year. This is expected to coincide with a population of 2.7 million.

An increasing preference for electric stoves is expected to result in a market share of over 50% (assumed to be 55.6%) by 2050. Additionally, due to the adoption of more energy-efficient technologies, the energy intensity of electric and gas stoves is projected to decrease by approximately half a percent per year. As household incomes rise, it is expected that 98% of households will invest in larger yet more efficient appliances, leading to an annual refrigeration intensity of 900 kWh per household by 2050. It is also anticipated that 99% of urban households will have access to electricity for lighting, with an annual projected intensity of 300 kWh per household by 2050. Conversely, the number of households using kerosene for lighting is expected to decrease to 0.07% by 2050. The use of other electricity-consuming equipment is projected to grow at a rate of 2.2% per year. Similarly, it is estimated that by 2050, 55.6% of households will use electric stoves, 96.9% will use LPG stoves, 3.2% will use wood stoves, 40.2% will use charcoal stoves, and 0.1% will use kerosene stoves for cooking, with a declining growth in the energy intensity of each technology.

Furthermore, Ghana aims to increase the percentage of rural households with electricity service to 90% by 2030 and 100% by 2050. It is anticipated that as incomes rise, the energy intensity of electric lighting will increase by 1% annually, while the number of households using kerosene for lighting is projected to decrease to 0.1% by 2050. The projected figures also indicate that the number of grid-connected (electrified) rural homes using a refrigerator will rise to 18.5% in 2030 and 26.1% in 2050.

Additionally, due to rural development activities, it is expected that by 2050, approximately 42.7% of both electrified and non-electrified households will use LPG stoves, 35.8% will use charcoal stoves, 22.8% of households will use wood stoves, and kerosene will be completely negligible.

4.1.2.2 Key Assumptions (Industry)

The total output of aluminium is not expected to change in the base year. This is because there was no aluminium production in 2010. However, production was 0.034, 0.041 and 0.038 tonnes for 2015, 2017 and 2020, respectively. By 2050, natural gas will account for 50% of power generation. In 2020, an additional plant for steel and iron production is expected to come online, increasing the industry's total output by 240 thousand tonnes per year. Cement production rose to 5 million tonnes in 2012 and further to 6.54 million tonnes in 2017. Other industries are anticipated to grow at a rate of 3% per year. The share of electricity generated from fuel is expected to increase to 70% by 2050.

4.1.2.3 Key Assumptions (Transport)

The demand for passenger travel (measured in passenger-km per person) is expected to increase slightly faster than average income levels, with a demand-income elasticity of 0.11. Additionally, the total population is projected to grow at a rate of 2.5% per year. The average income per capita is forecasted to increase at a rate of 5.3% per year from its current level of $1259, through 2050. Cars are expected to represent 85% of passenger road traffic by 2050.

The per capita demand for freight transport is anticipated to grow by 1.5% annually over the analysis period. Furthermore, the energy efficiency of all transport modes (both passenger and freight) is expected to improve by 1% per year through 2050, except for cars, which are projected to improve by 1.6% per year.

4.1.2.4 Commercial Sector Key Assumptions

Spaces in the commercial sector are expected to grow at a rate of 1% per year. Expected improvements in commercial building insulation standards would result in a decline of the useful energy by 1% per year until 2050. The average efficiency of daylight and ventilation by air is expected to reach 50% and 40% respectively, by 2050.

4.1.3 Transformation Analysis

4.1.3.1 Electricity Transmission and Generation

In the base year (2010), the installed electricity generation capacity of 2,165 MW with a planning reserve margin of 11.6% incurred T&D losses of 413 MW, representing 4% of the total capacity. In the Baseline scenario, these are expected to decrease to 25% by 2050. For natural gas pipelines (West Africa Gas Pipeline), losses are unavailable; however, they are expected to be minimal in 2050 for the baseline scenario.

Table 4.1.4 Characteristics of plant type

Plant type	Feedstock	Exogeneous Capacity (MW)	Efficiency (%)	Merit Order	Maximum Availability (%)	Historical Production (GWh)
Hydro	Hydro	1180	90	1	96	6995
Thermal	Natural gas	985	35	1	87	3171

Source: Energy Commission (2023)

In the baseline scenario, existing thermal plants will continue to run and new thermal plants will come online in 2025 (the introduction of the new thermal plant is dependent on whether the existing plants will be refurbished or retired). Renewable generation commenced in 2016 with 23 MW capacity (~ 20 MW for solar and 3MW for waste) and experienced an increase of 89.1 MW from 2016 to 2022 (a total generation capacity of 112.1 MW).

In the future, to meet growing demands and reduce fossil fuel dependency, various forms of renewable energy, including hydro, are expected to be part of the generation mix by 2030.

Table 4.1.5 Characteristics of renewable technologies

Type of renewable	Capacity (MW)	Efficiency (%)	Life span (Years)	Maximum Availability (%)
Hydro	150.03	90	100	96
Solar	741.3	20	30	70
Wind	50	40	20	70
Wave	327	30	50	70
Mini/micro	12	5	30	70
Waste-to-energy	112.1	25	30	70

Source: Energy Commission (2017, 2020, 2023), PCI Energy Solutions (2023)

4.1.3.2 Charcoal Production

Charcoal production in Ghana in the base year was dominated by wood as a feedstock. This is done by using the traditional earth mound kiln; however, advancements in technology and efforts to reduce greenhouse gas emissions have stimulated the introduction of modern briquetting techniques with an energy efficiency of 20% while that of the traditional earth mound kiln is 15%.

4.1.4 Mitigation and Policy Scenario: Demand-Sided Management (DSM)

This analysis focuses on strategies and policies that have been adopted to reduce emissions while meeting energy needs.

4.1.4.1 Key Assumptions: Energy efficiency measures and policy intervention for households

New efficiency standards for refrigerators are projected to decrease the average energy usage of refrigeration by 40%. By 2020, the energy usage per unit for urban households is anticipated to decrease by 5% compared to the current values, and by 15% by 2050. In rural households, energy usage is expected to decrease by 3% by 2020 and 10% by 2050. Various measures, including new lighting standards and utility demand-side management programs, are predicted to reduce the energy usage of electric lighting in urban households by 0.8% per year and to slow down the expected increase in electric lighting usage in rural areas from 1% per year (baseline scenario) to 0.5% per year. Additionally, the implementation of the solar light project in non-electrified rural homes is estimated to reduce the intensity of kerosene lighting by 1% per year.

4.1.4.2 Key Assumptions: Energy efficiency measures and policy intervention for industry

The government of Ghana is currently putting measures in place to use 100% natural gas as a source of energy for aluminium production by the Volta Aluminium Company (VALCO). In contrast, industries that produce cement, iron and steel, and other industries are expected to increase electricity penetration in their production and utilise energy efficiently. Aluminium production is expected to reach 0.1 million metric tonnes per year by 2050 as a result of measures being put in place for an integrated aluminium industry. The use of natural gas and electricity in the production process is expected to change, where electricity will account for about 75% of the fuel usage and 40% for natural gas. The energy intensities are expected to remain the same for natural gas and grow at a rate of 1% per annum for electricity.

The annual demand for steel and iron in the country is less than the annual production, which will keep the production constant till 2050. However, improvements in gadgets and the introduction of energy efficiency measures will lead to a declining growth rate of 0.5% per annum in energy usage. Cement production is expected to grow at a rate of 4% per year and a fuel intensity growth rate of 1% per year. The fuel used in the production process will remain electricity as a result of measures being put in place to reduce fossil fuel usage. Other industries are expected to remain the same.

4.1.4.3 Key Assumptions: Energy efficiency measures and policy intervention for transport

With measures in place to reduce fuel consumption, the government of Ghana has introduced the Bus Rapid Transit (BRT) system, which started operation in 2016 with about 245 buses. Similarly, the introduction of the electric vehicle initiative aims to reduce fossil fuel consumption in the transport sector. As a result, some assumptions were made; passenger car usage would reach 40% by 2030 and 80% by 2050, which would in turn reduce demand for gasoline-fuelled cars because there would be 35% electric cars by 2050. The intensity of gasoline-fuelled cars is expected to decline at a rate of 1.6% while that of electric cars increases at a rate of 1% per annum. The demand for passenger rail is expected to increase 4.7%, 19.8% and 25% in 2022, 2036, and 2050, respectively, with a 1.2% annual growth rate in fuel intensity.

Freight transport is expected to continue to grow at the same rate as in the baseline scenario. Rail freight transport is expected to be the same as in the baseline scenario as well; however, road freight transport is expected to decline to 75% in 2050 with a declining fuel intensity rate of 0.5% as part of measures to increase demand for rail fuel transport in the future.

4.1.4.4 Key Assumptions: Energy efficiency measures and policy intervention for Commerce

The introduction of green buildings for commercial spaces would decrease the demand for electricity for cooling at a rate of 1% annually. This is because, by 2050, efficient cooling appliances will see a 75% penetration and there will be an increase in preference of 20% for natural cooling methods (ventilation). Similarly, lighting in commercial spaces would experience a decline in energy intensity by 2050 as a result of efficient lighting measures and the proliferation of green building technologies. Efficient lighting or daylight are expected to be 55% and 40% by 2050 while the remainder is for inefficient or existing lighting.

4.1.4.5 Key Assumptions: Transmission and Distribution Losses in Electricity Generation

Electric transmission and distribution losses are anticipated to decrease to 3% by 2030 and further down to 2.5% by 2050. The implementation of load-levelling measures outlined in the DSM plan is expected to bring about gradual enhancements in the system load factor, which is projected to reach approximately 70% by 2050.

4.2 Results: Baseline Scenario Analysis and Electricity Generation

The results for this scenario are limited to the four sectors studied as well as the electricity generation sector.

4.2.1 Household Sector

Figure 4.2.1 presents the total energy demand from households by fuel type for the baseline scenario at 5-year intervals from 2010 to 2050.

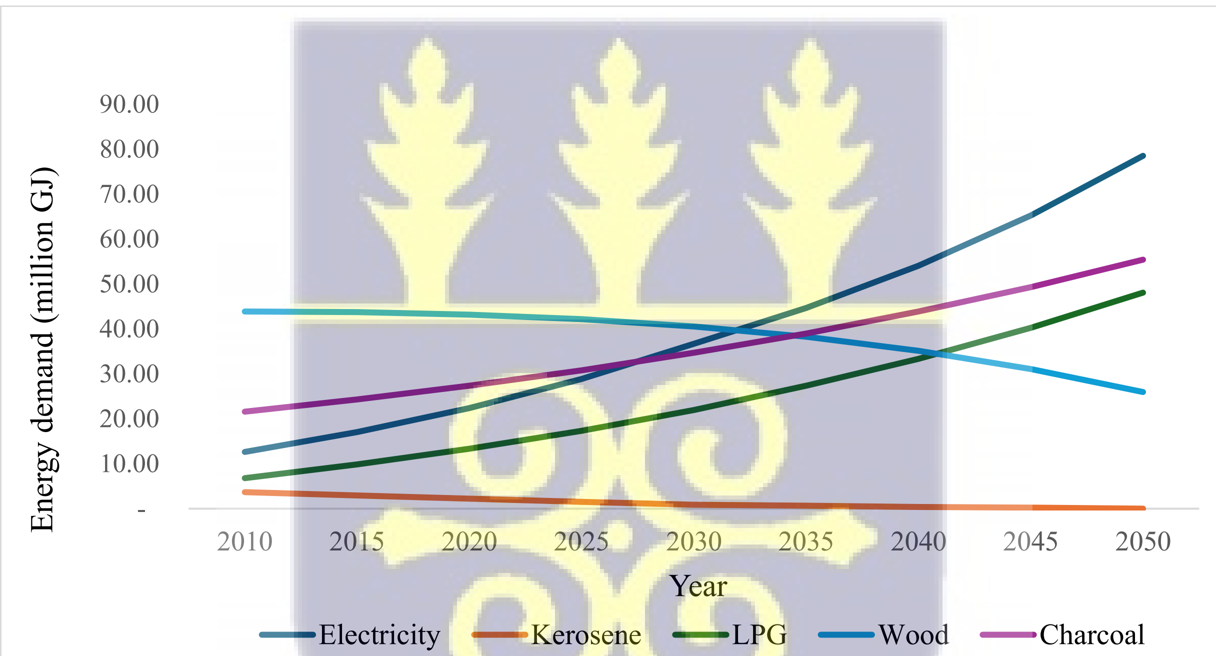

Figure 4.2.1 Total energy demand from households by fuel type for the baseline scenario
Source: Researcher's construct

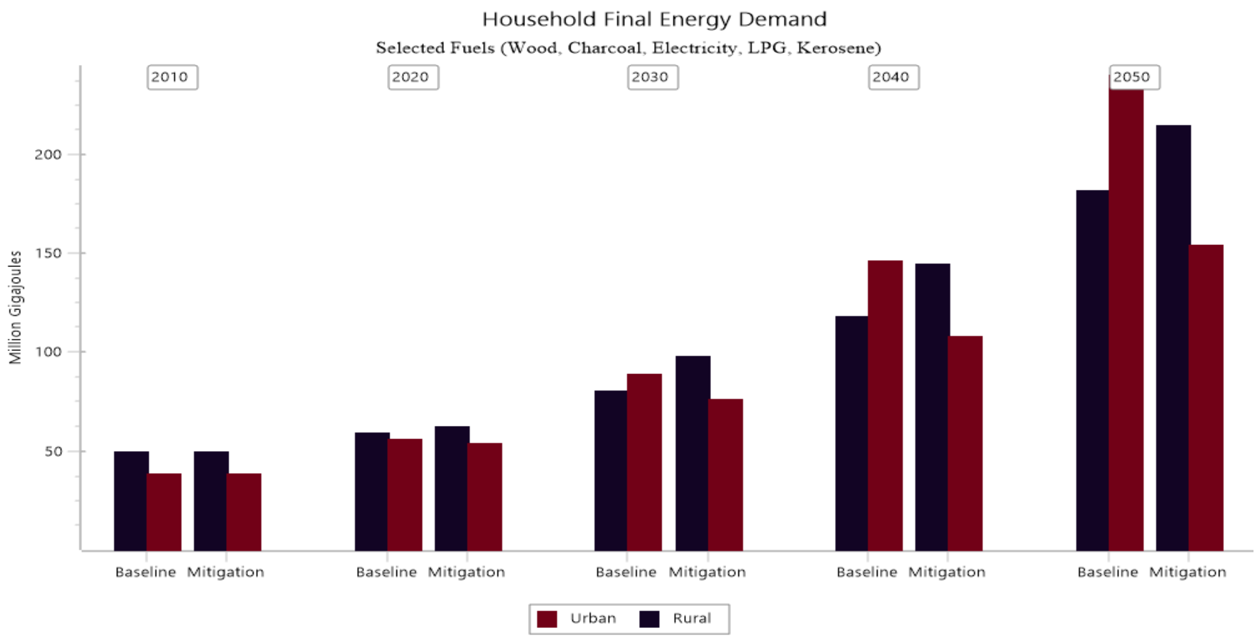

Figure 4.2.2: Scenario-based energy demand for different fuel types in urban and rural households

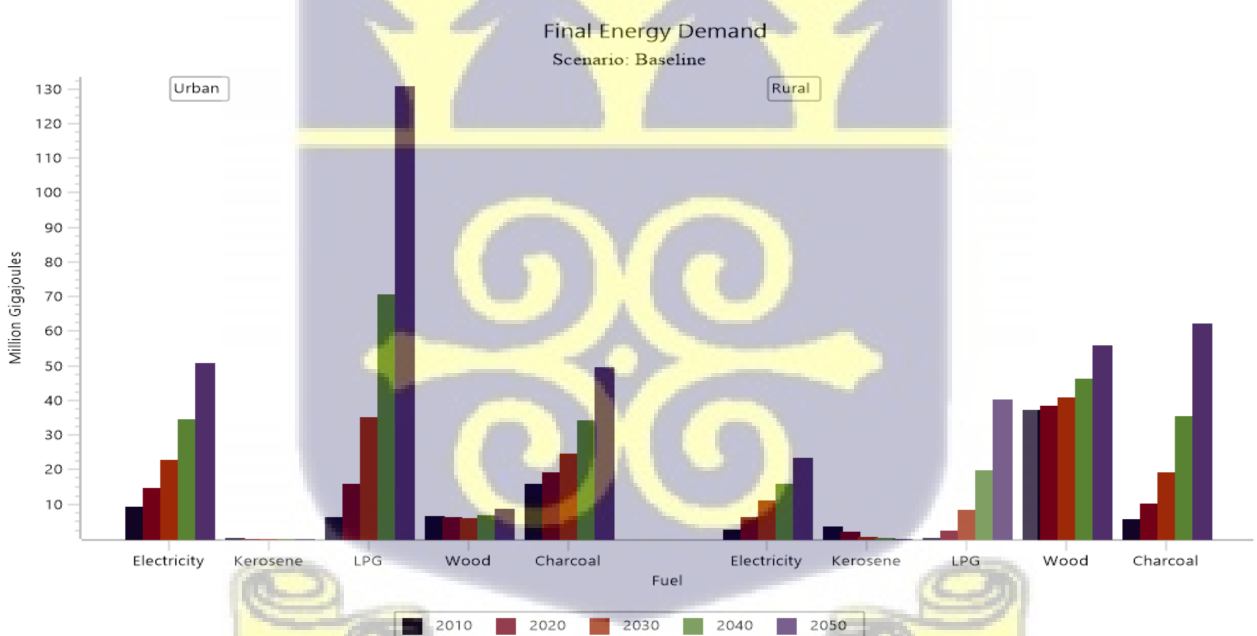

Figure 4.2.3: Scenario-based energy demand for different fuel types in urban and rural households

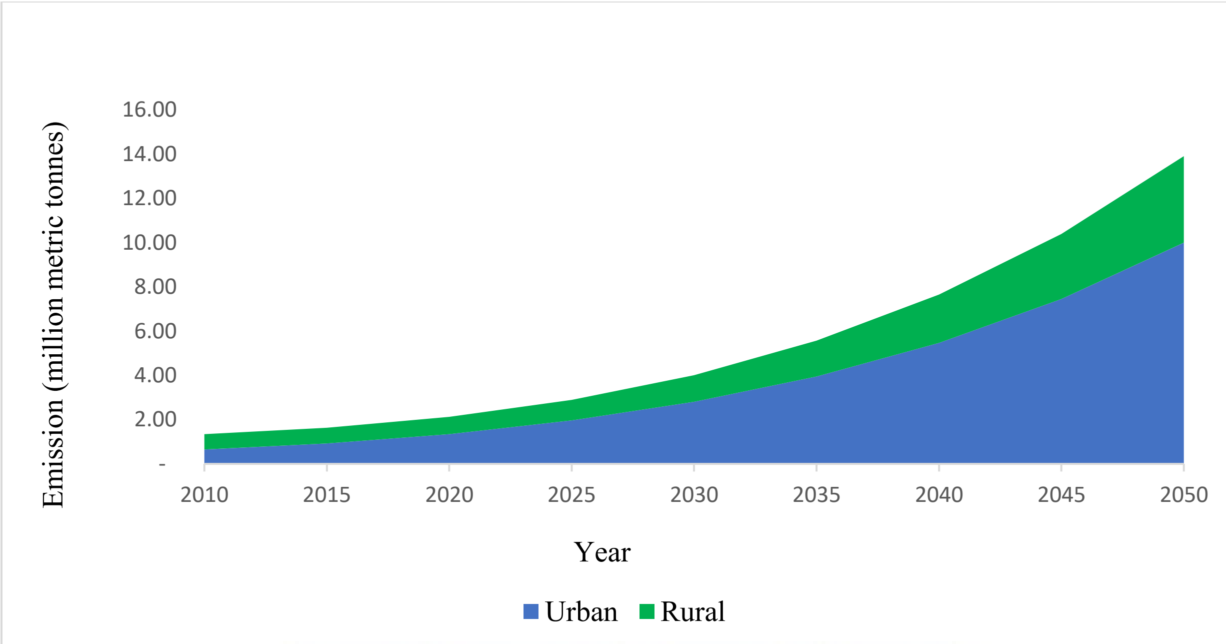

Figure 4.2.4 Greenhouse gas emissions from households for the baseline scenario
Source: Researcher's construct

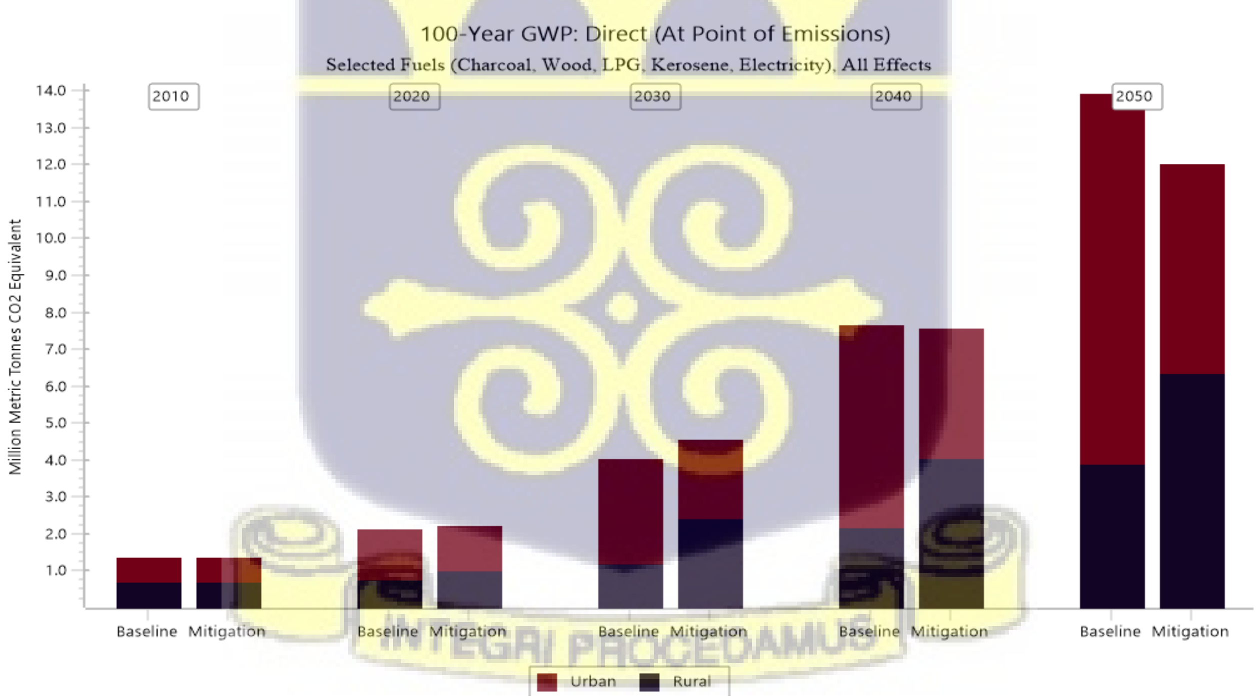

Figure 4.2.5: Scenario-based emissions for different fuel types in urban and rural households

4.2.2 Industrial Sector

Figure 4.2.6 provides the energy demand for the baseline scenario at 5-year intervals from 2010 to 2050. The total energy demand from the industrial sector in the base year is about 32.37 million gigajoules, equivalent to 773.1 ktoe.

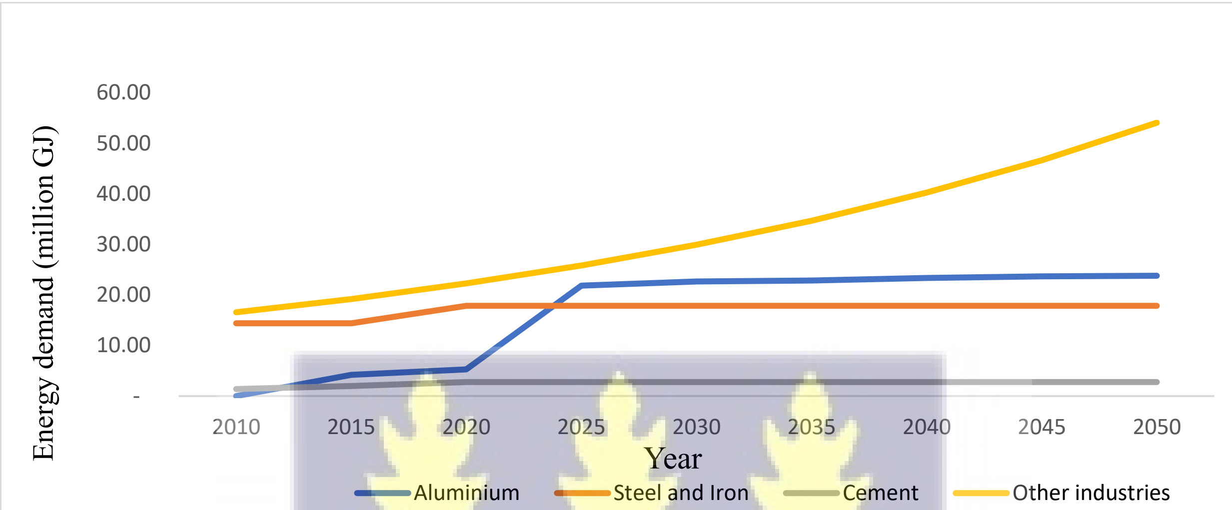

Figure 4.2.6 Total energy demand by industrial products for the baseline scenario
Source: Researcher's construct

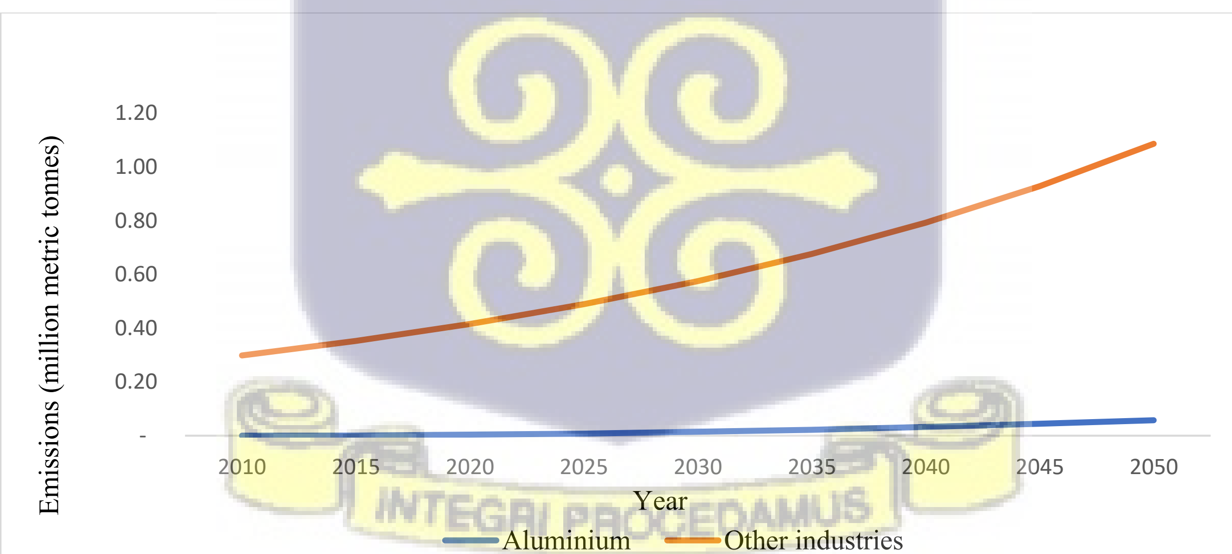

Figure 4.2.7 Greenhouse gas emission from industry for the baseline scenario
Source: Researcher's construct

4.2.3 Transport Sector

Figure 4.2.8 provides the energy demand for the baseline scenario at 5-year intervals from 2010 to 2050. The total energy demand from the transport sector in the base year is about 69.26 million gigajoules equivalent to 1654.2 ktoe.

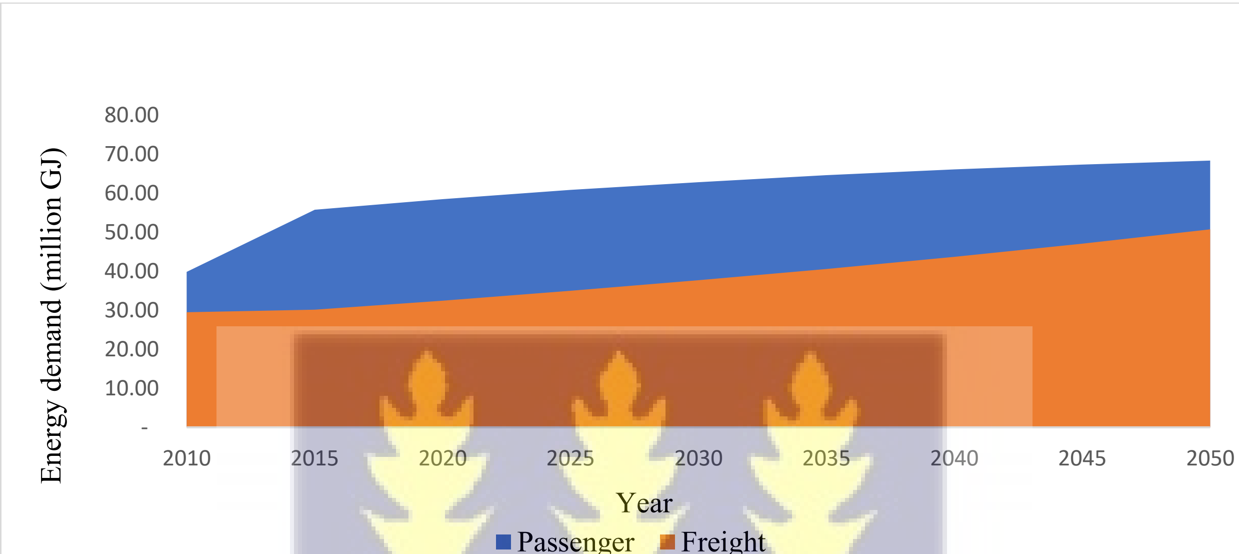

Figure 4.2.8 Energy demand from the transport sector for the baseline scenario

Source: Researcher's construct

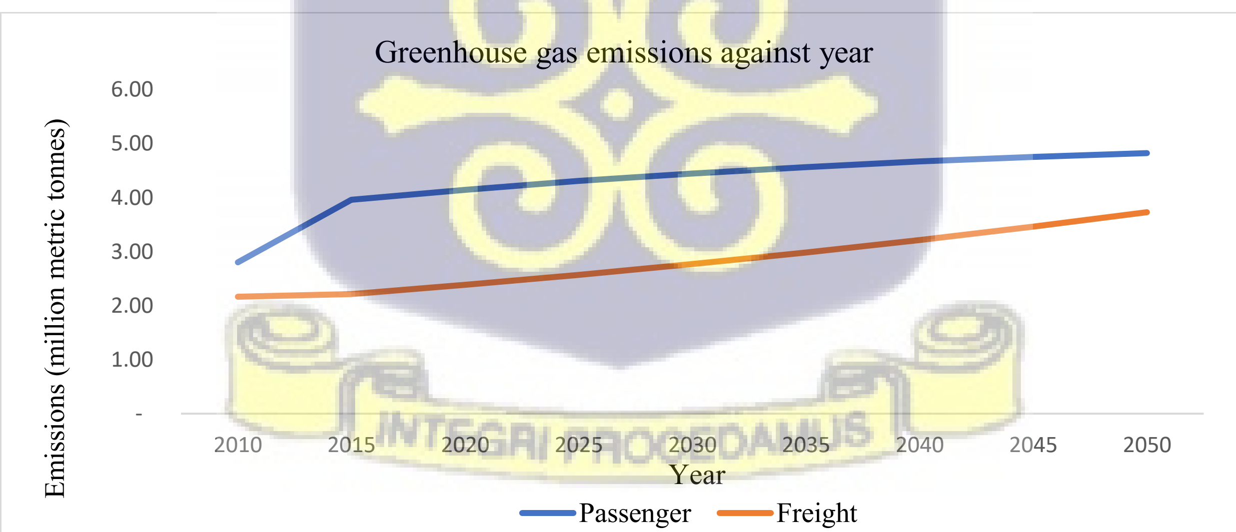

Figure 4.2.9 Greenhouse gas emissions from the transport sector for the baseline scenario
Source: Researcher's construct

Figure 4.2.9 provides the greenhouse gas emissions for the baseline scenario at 5-year intervals from 2010 to 2050 for the transport sector.

4.2.4 Commercial Sector

Figure 4.2.10 provides the energy demand for the baseline scenario at 5-year intervals from 2010 to 2050. The total energy demand from the commercial sector in the base year is about 11 million gigajoules, equivalent to 262.7 ktoe.

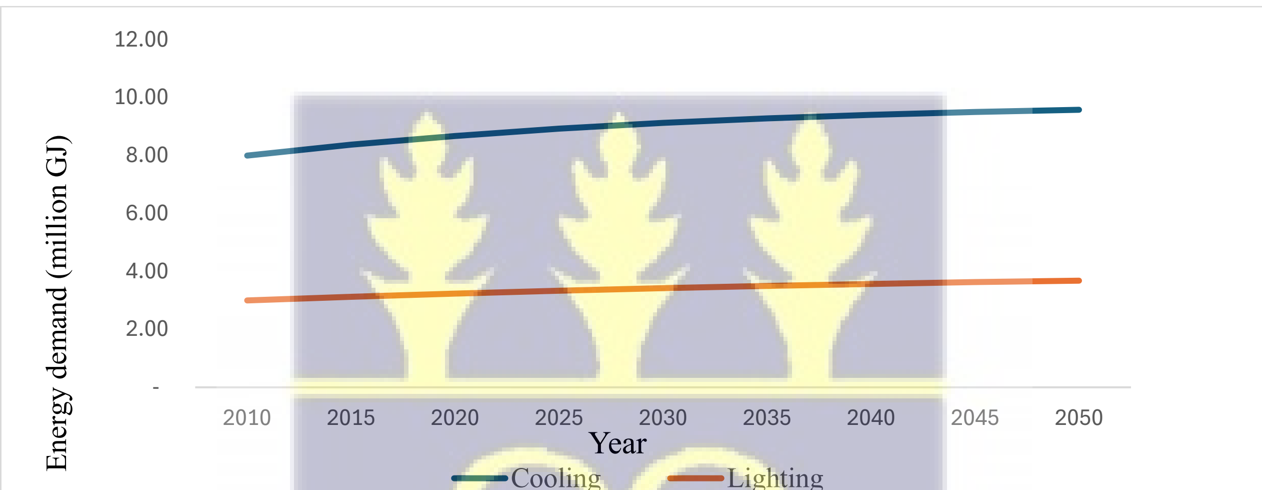

Figure 4.2.10 Energy demand from the commercial sector for the baseline scenario
Source: Researcher's construct

4.2.5 Electricity Generation

Figure 4.2.11 provides the energy output for electricity generation for the baseline scenario at 5-year intervals from 2010 to 2050.

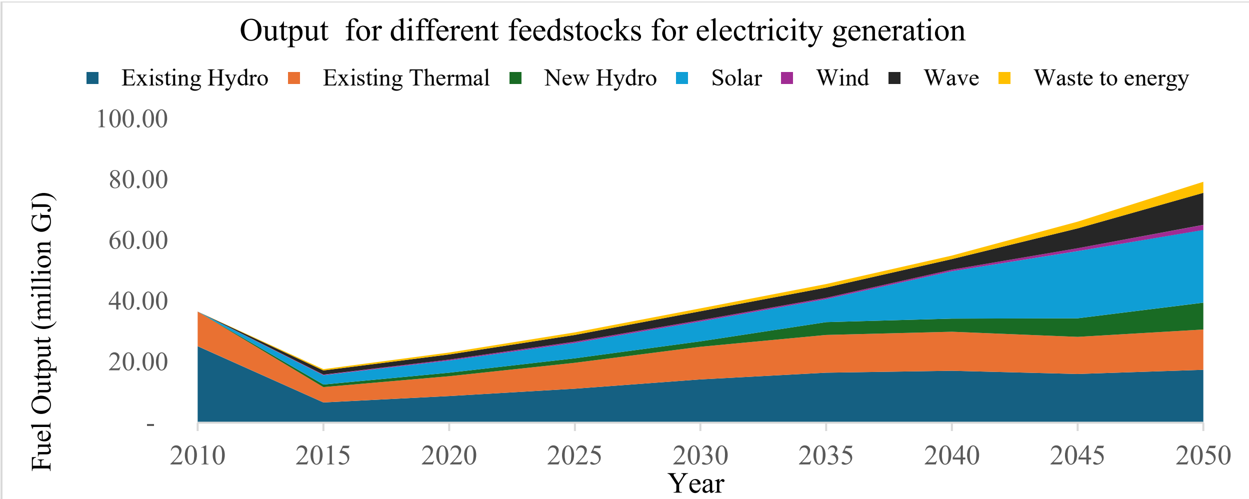

Figure 4.2.11 Feedstock output for electricity generation
Source: Researcher's construct

Figure 4.2.12 provides the greenhouse gas emissions for electricity generation at 5-year intervals from 2010 to 2050.

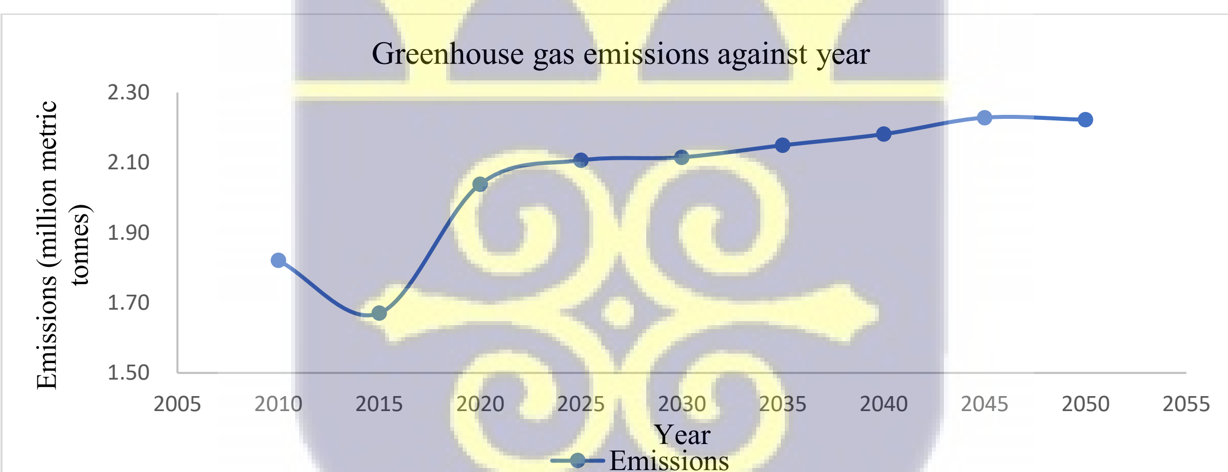

Figure 4.2.12 The trend in emissions from electricity generation
Source: Researcher's construct

4.3 Results: Mitigation and Policy Intervention Scenario Analysis

The results for this scenario are limited to the four sectors studied as well as the electricity generation sector.

4.3.1 Household Sector

Figure 4.3.1 presents the total energy demand from the household sector for the mitigation and policy scenario at 5-year intervals from 2010 to 2050.

Figure 4.3.1: Energy demand from households for the mitigation scenario

Source: Researcher's construct

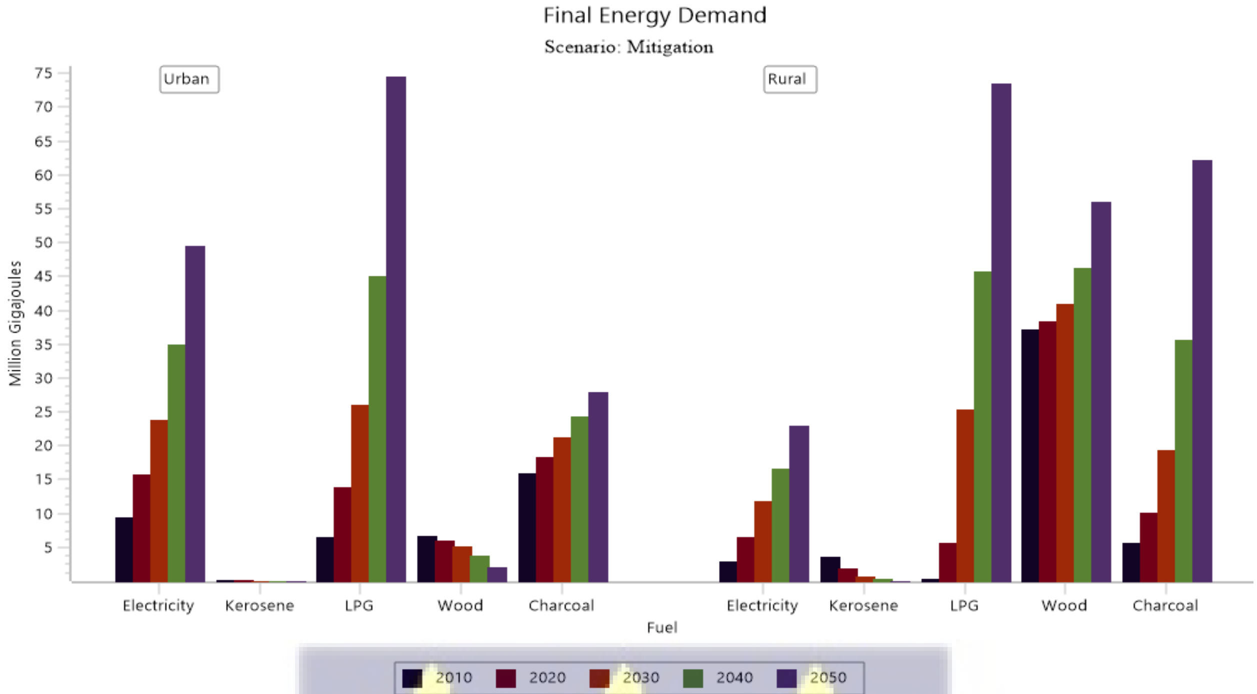

Figure 4.3.2: Urban and Rural Household Energy Demand for Different Fuel Types

Figure 4.3.2 provides the energy demand for the mitigation scenario for the household sector at 10-year intervals from 2010 to 2050.

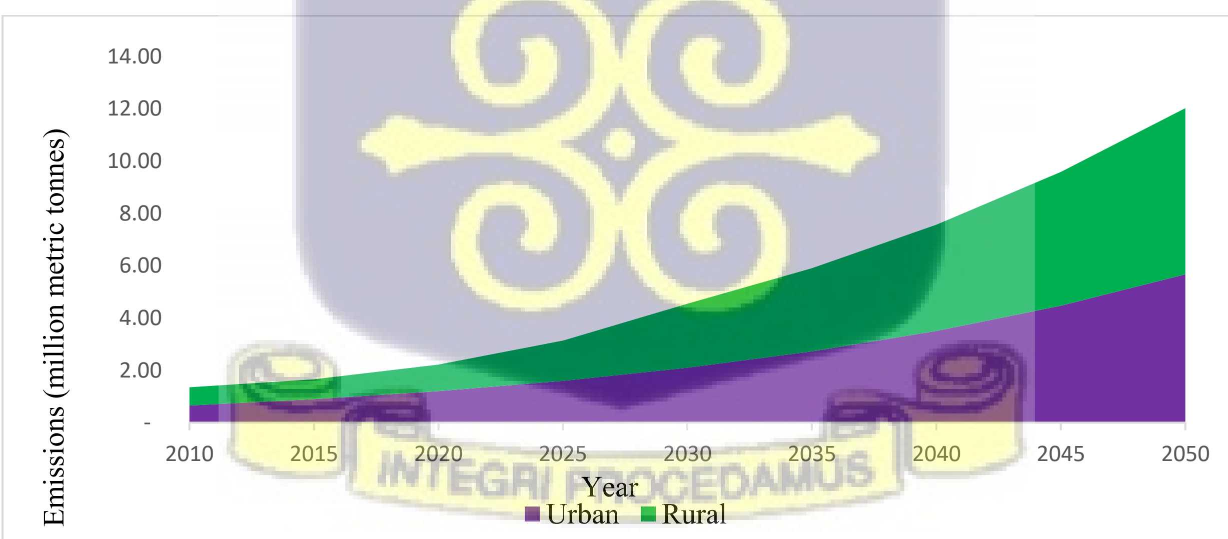

Figure 4.3.3 Emissions in the household sector for the mitigation scenario
Source: Researcher’s construct

4.3.2 Industry Sector

Figure 4.3.3 presents the total energy demand from the industry sector for the mitigation scenario at 5-year intervals from 2010 to 2050.

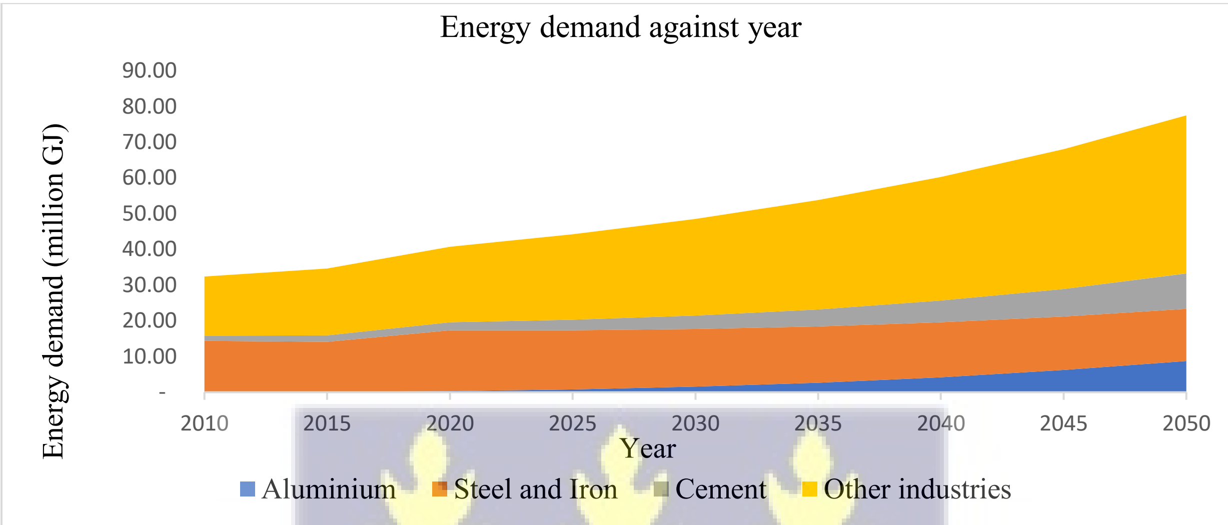

Figure 4.3.4 Energy demand from industry for the mitigation scenario
Source: Researcher's construct

Figure 4.3.4 provides the greenhouse gas emissions for the mitigation scenario for the industry sector at 5-year intervals from 2010 to 2050.

Figure 4.3.5 Greenhouse gas emissions for the mitigation scenario for the industry
Source: Researcher's construct

4.3.3 Transport Sector

Figure 4.3.5 presents the total energy demand from the transport sector for the mitigation scenario at 5-year intervals from 2010 to 2050.

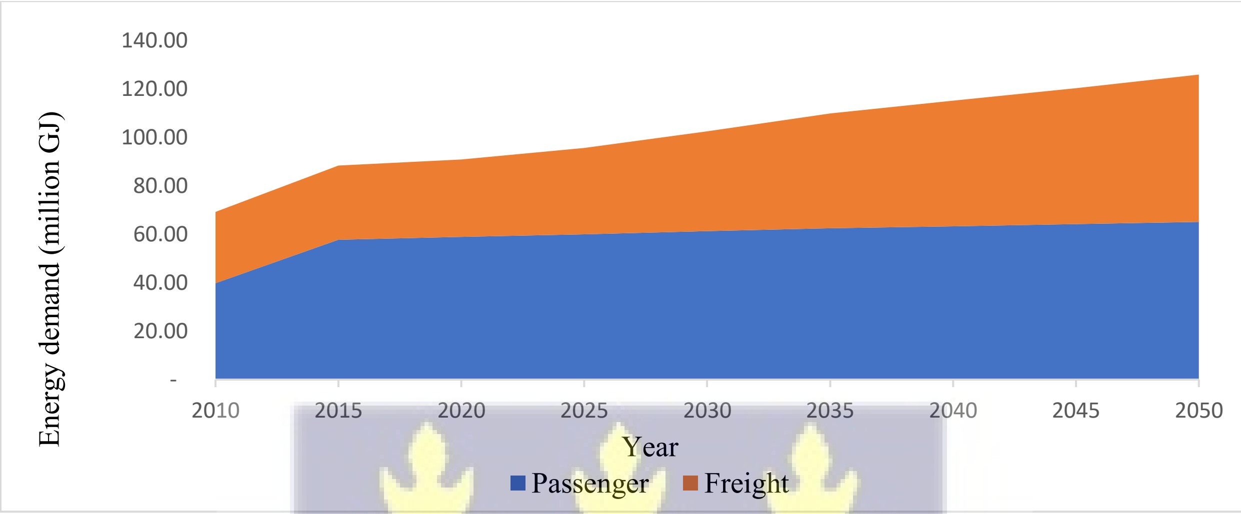

Figure 4.3.6 Energy demand from the transport sector for the mitigation scenario
Source: Researcher's construct

Figure 4.3.6 provides the greenhouse gas emissions for the mitigation scenario for the transport sector at 5-year intervals from 2010 to 2050.

Figure 4.3.7 Greenhouse gas emissions for the mitigation scenario for the transport
Source: Researcher's construct

Figure 4.3.7 presents the total energy demand from the commercial sector for the mitigation scenario at 5-year intervals from 2010 to 2050.

4.3.4 Commercial Sector

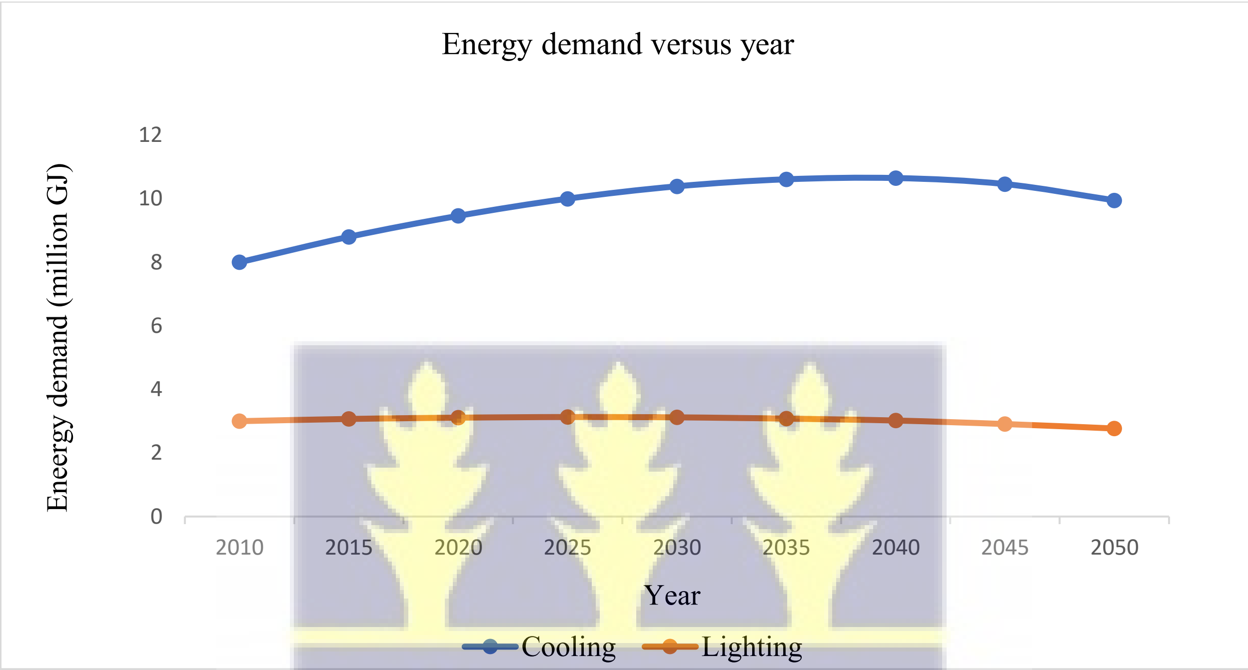

Figure 4.3.8 Energy demand from the lighting and cooling in commercial spaces
Source: Researcher's construct

CHAPTER 5 (FIVE)

DISCUSSION

5.0 Introduction

This chapter provides a comprehensive discussion of the findings derived from the analysis conducted using the Low Emission Analysis Platform (LEAP). The chapter is organized around the key discoveries of the study and their impact on energy policies and planning in Ghana. The discussion commences by emphasizing the primary scenarios created using the LEAP, which includes the business-as-usual (BAU) scenario and the mitigation and policy intervention scenario. Subsequently, the chapter outlines the outcomes of the energy demand analysis, revealing the anticipated surge in energy demand across various sectors of the Ghanaian economy: residential, commercial, industrial, and transportation. The chapter then discusses the energy supply analysis, which evaluates the potential for renewable energy development in Ghana, along with the role of fossil fuels and other energy sources in meeting future demand. This chapter also addresses the impact of energy efficiency measures and technological advancements on the energy supply mix under different scenarios. Essential to this chapter is the emissions analysis, which quantifies the potential for greenhouse gas (GHG) emissions reduction under the mitigation and policy scenario. The discussion emphasizes the primary drivers of emissions in Ghana's energy sector and strategies for mitigating these emissions, such as the adoption of renewable energy and the implementation of carbon pricing mechanisms. The chapter closes with a discussion of the policy recommendations that stem from the study's findings. The recommendations are specifically designed for the Ghanaian context and aim to assist policymakers in formulating a thorough energy policy that facilitates the shift towards a sustainable and low-carbon energy future. In all, this chapter offers a comprehensive examination of the outcomes generated by the LEAP model and their significance for Ghana's energy industry. The discussion is reinforced by data visualizations, including graphs and tables, to improve the clarity and significance of the results.

5.1 Scenarios

The results are influenced by two major scenarios employed for the analysis: baseline scenario and mitigation and policy scenarios. These scenarios presented different outcomes based on varying assumptions and interventions. Baseline scenarios typically represent a "business as usual" approach, while mitigation and policy scenarios explore the impact of specific actions or policies on the outcomes. These contrasting scenarios provided information on energy demand and greenhouse gas emissions for the four main energy demand sectors: household, industry, transport, and commerce.

5.2 Energy Demand and Greenhouse Gas Emissions in Households

Table 1A.1 of **Appendix A** presents the total energy demand from the household sector for the business-as-usual scenario. As a result of population growth, the energy demand in 2050 is expected to increase by 233.7% to the base year value; this is to say that the total energy demand from the household sector is projected to be 208 million gigajoules which is equivalent to 4968 ktoe. Energy demand in the household sector is dominated by urban households (**Figure 4.2.2**), and electricity is expected to be the most used fuel from 2035 to 2050. Preference for LPG and charcoal increased over the years, while wood and kerosene experienced a decline.

The associated emissions are also expected to increase linearly as demand for energy increases as presented in **Table 1A.3** of **Appendix A**. Just as in the case of energy demand, household emissions are mostly from urban households, however, due to different cooking technologies (the use of LPG, charcoal and firewood). Consequently, the projected emissions for the end year, 2050 is 13.91 $MtCO_{2e}$, more than 1000% of the base year emission of 1.35 $MtCO_{2e}$.

The household sector's mitigation and policy scenarios have shown a higher demand for energy with lower greenhouse gas emissions from 2010 to 2050 compared to the baseline scenario, as indicated in **Table 1A.2** of **Appendix A** and **Figures 4.2.2 and 4.3.1** The reduction in emissions can be attributed to energy efficiency measures and policies related to cooking, lighting, and refrigeration. Although energy demand in urban households is higher compared to the baseline scenario, emissions from rural households have increased significantly from 2030 for the mitigation and policy scenarios, as outlined in **Table 1A.5** of **Appendix A**. This increase can be linked to the cooking technologies in rural areas, with the expected use of improved charcoal, wood, and mud cookstoves, in contrast to urban areas where clean cooking using LPG is expected to be the primary method.

5.2.1 Rural vs. Urban Household Energy Consumption Patterns

Findings reveal significant disparities between rural and urban households in both energy consumption volumes and fuel types used. Urban households typically have greater access to and rely more on modern energy carriers such as electricity and Liquefied Petroleum Gas (**Figures 4.2.2 and 4.2.3**). For example, approximately 70% of urban households primarily use electricity for lighting and appliances, while LPG accounts for 83.7% of urban cooking fuel use. In contrast, rural households remain heavily dependent on traditional biomass fuels, with wood and charcoal comprising over 60% of their cooking energy mix (**Figure 4.2.3**).

Urban households generally have a higher ownership rate of electrical appliances, contributing both to higher electricity consumption and energy efficiency potential through the adoption of energy-saving devices. Meanwhile, rural households face greater affordability and infrastructure constraints limiting modern energy adoption. Our model's disaggregated approach captures these urban-rural distinctions, highlighting that policies favouring electrification and clean cooking technologies will yield differentiated benefits across regions, particularly improving health and economic outcomes in underserved rural areas.

5.2.2 Equity Considerations Within the Household Sector

Income, education, and dwelling type also substantially affect energy use patterns within households. Higher income quintiles in both rural and urban areas tend to consume more electricity and LPG, moving up the "energy ladder," while lower income groups continue reliance on polluting biomass fuels, exacerbating indoor air pollution and health risks (Amankwah et al., 2016; Yiran, 2020). This underscores the importance of targeted subsidies and financing mechanisms to enhance clean energy access among low-income households.

5.3 Energy Demand and Greenhouse Gas Emission in Industries

Demand for energy in the industrial sector is mainly from other industries, followed by steel and iron, then cement and aluminium. The demand for energy in the production of aluminium and in other industries is projected to increase steadily, while the demand for steel and cement production is expected to remain constant from 2020 to 2050. These projections are based on the assumptions made for iron, steel, and cement production. The total energy demand in 2050 is forecasted to reach 81.69 million GJ, nearly triple the value of 32.27 million GJ in the base year.

Under the mitigation and policy scenario, the overall energy demand is expected to decrease compared to the baseline scenario. However, the energy demand from different sectors, including other industries, follows a similar pattern to the baseline scenario. Notably, other industries continue to be the largest consumers of energy, followed by steel and iron production, cement production, and aluminium production. The energy demand for cement and aluminium fluctuates over the years. The total energy consumption across industries is projected to be 77.51 million GJ in 2050, resulting in a total energy saving of 4.18 million GJ. This reduction in consumption is attributed to the implementation of mitigation and policy measures aimed at improving industrial efficiency and decreasing reliance on fossil fuels within the sector.

Tables 1B.1 and 1B.2 in **Appendix B** showcase the greenhouse gas emissions from industries under the baseline scenario and the mitigation and policy scenario, respectively. It is noted that the emissions for the mitigation and policy scenario are lower compared to the baseline scenario. Specifically, the total emissions for the baseline scenario in 2050 are projected to be 1.14 $MtCO_{2e}$, while those for the mitigation scenario are estimated at 0.75 $MtCO_{2e}$. Consequently, it can be inferred that the total emissions avoided in 2050 amount to 0.39 $MtCO_{2e}$.

5.4 Energy Demand and Greenhouse Gas Emission in Transportation

In 2050, the total energy demand from the transport sector in the baseline scenario is projected to be 119.11 million GJ, compared to 126.05 million GJ in the mitigation and policy scenario. It is evident that energy demand in passenger transportation exceeds that of freight transport across all scenarios. Notably, energy demand for freight transport is expected to increase by approximately 19% in 2036 due to government efforts to promote rail freight transport. Conversely, efforts to reduce energy consumption for passenger transport, such as the exploration of alternative low-carbon fuels like biofuel, fuel cell technology, and electricity for buses and cars, are anticipated to result in a decrease. As a consequence, emission patterns align with those of households and industries, showing lower emissions in the mitigation and policy scenario compared to the baseline scenario. Specifically, the total energy demand in 2050 for the mitigation and policy scenario and the baseline scenario are estimated to be 8.02 $MtCO_{2e}$ and 8.56 $MtCO_{2e}$, respectively, resulting in an avoided emission of 0.54 $MtCO_{2e}$.

5.5 Energy Demand and Greenhouse gas Emission in Commerce

Energy demand in the commercial sector for the mitigation and policy scenario is impacted by the government's efforts to promote green buildings, particularly for office spaces, as well as the use of energy-efficient lighting and cooling appliances. The energy consumption for the baseline scenario is lower than that of the mitigation and policy scenario from 2015 to 2045. However, in 2050, the commercial sector experienced an energy demand of 13.26 million GJ, compared to the baseline scenario's 12.72 million GJ. Emissions for the commercial sector are reflected in the electricity production.

5.6 Greenhouse Gas Emissions from Electricity Generation

Table 5.6.1 Emissions from Electricity Generation for baseline and mitigation scenarios ($MtCO_{2e}$)

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	1.82	1.67	2.04	2.11	2.12	2.15	2.18	2.23	2.22
Mitigation	1.82	1.64	2.02	2.17	2.12	2.16	2.19	2.22	2.22
Avoided	0.00	0.03	0.02	-0.06	0.00	-0.01	-0.01	0.01	0.00

The emissions from electricity generation result from the use of fossil fuels, especially natural gas, in thermal plants. Although there have been some reductions in emissions over the years due to government efforts to promote the use of traditional energy sources and to increase the penetration of renewable energy in the energy mix by 30% by 2030, the actual reduction in emissions is minimal. This emphasises the necessity for further development in clean energy technologies and the implementation of more aggressive policies to reduce emissions from electricity generation.

5.7 The Energy Demand and Greenhouse Gas Emission Nexus

As the demand for energy continues to rise across all sectors, it is essential to ensure an adequate supply of energy from various sources. Reviewing the data in **Tables 5.7.1 and 5.7.2**, it becomes clear that the increasing demand for energy is closely linked to a rise in greenhouse gas emissions. This underscores the urgent need to explore and invest in sustainable energy sources and technologies to mitigate the environmental impact of rising energy requirements. Undoubtedly, more sustainable and environmentally friendly energy future can be achieved by prioritizing renewable energy and implementing energy-efficient practices across all sectors of the economy.

Table 5.7.1 Total sector energy demand for baseline and mitigation scenarios (million GJ)

Year	**Baseline Scenario**				**Mitigation and Policy Scenario**			
	Household	**Industry**	**Transport**	**Commerce**	**Household**	**Industry**	**Transport**	**Commerce**
2010	88.99	32.37	69.26	11.00	88.29	32.37	69.26	11.00
2015	97.83	39.81	85.91	11.50	99.84	34.63	88.46	11.87
2020	108.47	48.21	90.94	11.92	116.81	40.76	90.98	12.58
2025	120.69	52.13	95.8	12.26	140.97	44.22	95.67	13.13
2030	134.80	56.91	100.54	12.55	174.40	48.52	102.57	13.51
2035	149.95	61.75	105.20	12.79	209.56	53.81	109.94	13.70
2040	166.85	67.65	109.82	12.98	252.58	60.26	115.30	13.67

2045	186.11	74.24	114.44	13.14	305.02	68.08	120.42	13.37
2050	208.00	81.69	119.11	13.26	368.70	77.51	126.05	12.72

Table 5.7.2 Total sector emission for baseline and mitigation scenarios ($MtCO_{2e}$)

Year	**Baseline Scenario**				**Mitigation and Policy Scenario**			
	Household	**Industry**	**Transport**	**Commerce**	**Household**	**Industry**	**Transport**	**Commerce**
2010	1.35	0.30	4.97	-	1.35	0.30	4.97	-
2015	1.63	0.35	6.18	-	1.65	0.33	6.35	-
2020	2.13	0.42	6.53	-	2.21	0.36	6.41	-
2025	2.90	0.50	6.88	-	3.14	0.40	6.64	-
2030	4.01	0.59	7.22	-	4.54	0.45	7.04	-
2035	5.57	0.70	7.55	-	5.90	0.50	7.40	-
2040	7.66	0.83	7.88	-	7.56	0.57	7.60	-
2045	10.39	0.97	8.22	-	9.58	0.65	7.79	-
2050	13.91	1.14	8.56	-	12.02	0.75	8.02	-

Table 5.7.3 Total energy demand, total GHG emissions, and avoided emissions

Year	**Total energy demand (million GJ)**		**Total GHG emissions ($MtCO_{2e}$)**		**Avoided emissions ($MtCO_{2e}$)**
	Baseline	**Mitigation**	**Baseline**	**Mitigation**	
2010	201.62	200.92	6.62	6.62	0.00
2015	235.05	234.80	8.16	8.33	-0.17
2020	259.54	261.13	9.08	8.98	0.10
2025	280.88	293.99	10.28	10.18	0.10
2030	304.8	339.00	11.82	12.03	-0.21
2035	329.69	387.01	13.82	13.80	0.02
2040	357.3	441.81	16.37	15.73	0.64
2045	387.93	506.89	19.58	18.02	1.56

2050	422.06	584.98	23.61	20.79	2.82

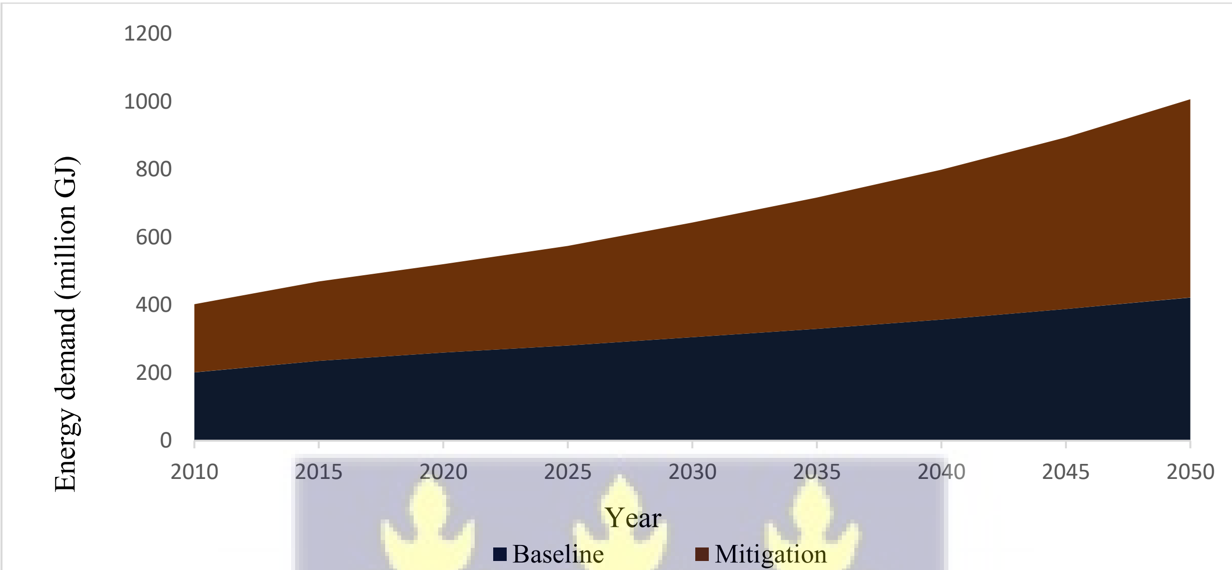

Figure 5.7.1 Total expected energy demand
Source: Researcher’s construct

Figure 5.7.2 Total expected GHG emissions
Source: Researcher's construct

5.8 Energy Supply Analysis

The Integrated Power Sector Master Plan (2023) outlines a planned reserve margin of approximately 18% for electricity generation. This reserve margin, when factored into energy consumption for this study, will significantly influence the total energy production necessary to fulfil demand across the four key areas of the energy sector. With a baseline scenario indicating a total demand of 10080.7 ktoe, it is projected that 11895.2 ktoe of energy will be generated to meet this demand by 2050. Similarly, in the mitigation scenario with a total demand of 13972 ktoe, a production of 16487 ktoe of energy will be required as outlined in **Table 5.8.1**. Meeting this demand will involve harnessing energy from various sources, including fossil fuels in cases where renewable energy uptake falls short. This, in turn, will impact emissions levels. It will be necessary to coalesce strategies, including increasing the capacity of renewable energy sources such as wind, solar, and hydroelectric power. Balancing the energy mix to minimise environmental impact while meeting the growing demand will be a key focus in achieving the targets set forth in the National Energy Transition Framework (2023).

Table 5.8.1 Expected produced energy in 2050 for baseline and mitigation scenarios (ktoe)

	Energy Demand (ktoe)		**Expected Energy Production (ktoe)**	
Scenario	**Baseline**	**Mitigation**	**Baseline**	**Mitigation**
2050	10080.7	13972.0	11895.2	16487.0

In contrast, **Table 5.8.2** presents the actual total energy supply obtained from the LEAP analysis, further categorised by source in **Table 1E.1** of **Appendix E**. Wood is anticipated to remain the predominant energy source, followed by crude oil, solar, wave, hydro, natural gas, municipal solid waste, and wind. Observation reveals that the total energy supplied for the mitigation and policy scenario exceeds that of the baseline scenario, indicating increased energy production necessary to meet growing energy demands. By 2030, it is projected that energy demand from the four sectors analysed in this study will represent approximately 45% of the total energy supply, declining to nearly 40% in 2040 and 35% in 2050. The reduction in energy demand within the sector can be largely attributed to the mitigation and policy measures implemented and the assumptions underlying this study.

Table 5.8.2 Total energy supply, demand and emissions (million GJ)

Year	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Baseline scenario									
Supply	260.1	473.6	542.8	627.6	738.0	863.6	1007.6	1188.0	1406.7
Demand	201.6	235.1	259.5	280.9	304.8	329.7	357.3	387.9	422.1
Emission	6.62	8.16	9.08	10.28	11.82	13.82	16.37	19.58	23.61
Mitigation and policy scenario									
Supply	260.1	474.7	551.9	643.0	770.3	923.2	1107.9	1345.8	1641.3
Demand	200.9	234.8	261.1	294.0	393.9	387.0	441.8	506.9	585.0
Emission	6.62	8.33	8.98	10.18	12.03	13.8	15.73	18.02	20.79

Figure 5.8.1 Total energy supply, demand and emissions for all scenarios

5.9 Key Findings and Implications of Results

The results of this study project a steady increase in energy demand between 2010 and 2050 across all sectors, driven by economic and population growth. Household energy demand is anticipated to dominate, accounting for 63% of the total, followed by transport (21.5%), industry (12.3%), and commerce (2.2%) under the mitigation and policy scenario. Similarly, in the baseline scenario, household demand is expected to comprise 49.3% of the total, followed by transport (28.2%), industry (19.4%), and commerce (3.1%). In the base year, the share of energy demand in households, industry, transport, and commerce is 44.1%, 16.1%, 34.4%, and 5.4% respectively.

The total emissions from the key energy demand sectors, including those associated with electricity generation, are projected to be 8.44 $MtCO_{2e}$ and 25.81 $MtCO_{2e}$ for the baseline scenario and 22.99 $MtCO_{2e}$ for the mitigation and policy scenario. Specifically, the share of emissions for household, industry, transport, and electricity generation is estimated to be 16%, 3.6%, 58.9%, and 21.6%. As household energy demand rises, emissions from this sector are projected to account for about 52.4% of the total in 2050, followed by transport (34.9%), electricity generation (9.6%), and industry (3.3%). As shown in **Figure 1A.1**, CO_2 is the predominant greenhouse gas (GHG) in the household sector, followed by CH_4 and N_2O from 2010 to 2050. This trend is consistent across all sectors examined in this study, with CO_2 dominating the total emissions. It's worth noting that energy demand and emissions are intricately linked – as demand increases, emissions also increase linearly.

It is anticipated that the overall energy supply will continue to grow over the years, with wood remaining the dominant source. To move towards a low carbon-intensive economy, non-conventional sources such as solar must become the predominant energy supply. Additionally, it is expected that the energy sector will consume over one-third of the total supply in the future, despite a decrease in demand over time.

In comparing the base year emissions from this study to the emissions reported in Ghana's greenhouse gas inventory report (2021), there is a notable difference. The report records 12.79 $MtCO_{2e}$, whereas the study indicates 8.44 $MtCO_{2e}$. A similar disparity is observed when comparing the data from the National Energy Statistics report (2023) to the findings of this study. National Energy Statistics report (2023) recorded the base year total energy consumption from the household, industry, transport and Commercial as 2595 ktoe, 785 ktoe, 1843 ktoe and 254 ktoe, while results from this study present 2125.5 ktoe, 773.1 ktoe, 1654.2 ktoe and 262.7 ktoe, respectively. The recorded base year total energy consumption from various sectors differs marginally from the study's results. While some sectors were not covered in this study, it is apparent that there are inconsistencies in the data input and underlying assumptions.

It is important to carefully examine the discrepancies between the data collected in this study and the official reports. By identifying the specific sectors that were not covered in this study and comparing the assumptions made with the established standards, a more accurate assessment can be achieved. Additionally, conducting a thorough review of the data collection process and ensuring that the methodologies align with best practices will help to address these anomalies and improve the overall reliability of the study's findings.

5.10 Comparison with Existing Literature and Models

This research builds upon and extends the existing body of knowledge on energy supply and demand forecasting in Ghana, particularly within the context of climate change mitigation and sustainable development. The application of the Low Emission Analysis Platform (LEAP) model offers methodological rigour and policy relevance that distinguish it from earlier studies.

Previous Ghanaian energy demand studies, such as those by Frimpong et al. (2017) and the Energy Commission (2020, 2022), primarily provided aggregate national projections without substantial sectoral or spatial breakdowns. By contrast, this study delivers a detailed sectoral decomposition—household, transport, industry, and commerce—with quantified shares of total energy demand projected for 2050. For example, under the Business-As-Usual (BAU) scenario, households account for approximately 49.3% of the total energy consumption, transport 28.2%, industry 19.4%, and commerce 3.1%. This granularity aligns with Takase et al. (2022), who emphasised the importance of sector-specific data for nuanced policy interventions in Ghana.

The urban-rural disaggregation further enhances the study's policy relevance. Urban households are projected to demonstrate increased electricity consumption and renewable energy adoption, while rural households remain reliant on biomass and other traditional fuels (**Table 1A.3 of Appendix A**). This finding corresponds with Foday et al. (2023) and IRENA (2023) reports highlighting stark disparities in energy access and the need for targeted off-grid renewable solutions in rural Ghanaian regions.

While studies such as Kuriakose et al. (2022) and Ghana National Greenhouse Gas Emission Report (2019) highlighted potential policy impacts, they did not systematically embed national policy pathways within model parameters as comprehensively as done herein. The Mitigation scenario projects household energy demand rising to 63% of total energy consumption by 2050, reflecting electrification progress aligned with policy goals.

Furthermore, the detailed sectoral and spatial approach of this research presents a more holistic and realistic portrayal of Ghana's energy transition compared to earlier models focusing primarily on electricity supply-demand balance (Energy Commission, 2020). It accounts for cooking fuels, transport energy use, and industrial consumption, reflecting the complexity of energy needs across economic sectors. This integrated perspective resonates with recent Sub-Saharan African modelling efforts (Gebremeskel et al., 2023; Conteh et al., 2023), underscoring multi-sectoral interdependencies essential for sustainable energy transitions.

A comparative review of emission trajectories reveals projections that are consistent with regional benchmarks, while also providing enhanced detail. For instance, the BAU pathway projects CO_2 emissions increasing by approximately 85% between 2010 and 2050, driven largely by household and transport sectors, whereas the Mitigation scenario achieves a relative reduction of 27% in emissions by 2050 vis-à-vis BAU. These quantitative results build upon and add depth to analyses by Abokyi et al. (2021) and Nnene et al. (2023), who reported broad emissions trends but with less disaggregated sectoral insights.

This study explicitly addresses the limitations identified in previous studies regarding data transparency and practical policy linkage. The study documents data sources, interpolation methods, and scenario development with clarity previously lacking in Ghanaian energy modelling literature. By integrating quantitative findings with national policy and equity considerations, it offers actionable evidence for policymakers aiming to balance economic growth, energy security, and climate commitments.

CHAPTER 6 (SIX)

CONCLUSION

6.0 Introduction

This chapter provides a summary of the main findings and insights obtained from the study on Ghana's energy supply and demand using the Low Emission Analysis Platform (LEAP). The research examined low-emission strategies aligned with national and international climate commitments. It revisits the primary research questions and objectives, reflects on the implications for energy policy and planning, emphasises the importance of embracing renewable energy sources, outlines policy recommendations, and offers insights into the study's limitations and recommendations for future research. This chapter in general, emphasises the importance of well-informed decision-making in Ghana's energy sector to promote a sustainable, low-emission future.

6.1 Summary of Findings

6.1.1 Modelling and Forecasting Ghana's Energy Future to 2050: A Low-Emission Focus

The main objective of this study is to analyse different scenarios for the development of Ghana's energy sector, with a specific focus on reducing greenhouse gas emissions. Leveraging the Low Emission Analysis Platform (LEAP) model, the research offers valuable insights into potential strategies for attaining a low-emission energy future in Ghana by 2050. In general, the study divulged the need to consider GHG emissions from the energy sector and the potential avenues for sustainable development and reduction in these emissions.

One of the most notable discoveries of the study is the anticipated surge in energy demand in Ghana. The analysis forecasted a substantial escalation in energy demand by 2050, primarily propelled by population growth, urbanisation, and economic advancement. Under a business-as-usual (BAU) scenario, the study approximates that energy demand could soar to about 422.06 million GJ (equivalent to 117238.8 GWh) by 2050, signifying an annual growth rate of roughly 9.7%. Similarly, the mitigation and policy scenario projects a 584.98 million GJ (equivalent to GWh) in 2050, which indicates a 14.3% average growth per annum. However, the average annual growth in emissions for both the BAU and mitigation and policy scenarios is about 17.3% and 15.5% respectively, underscoring the exigency for strategic planning to ensure that energy supply aligns with this burgeoning demand while focusing on low-emission measures.

Accordingly, the study emphasises the pivotal role of renewable energy in shaping the future of Ghana's energy sector. It posits that under the mitigation and policy scenario, the share of renewable energy in the electricity generation mix could experience a substantial upsurge, potentially surpassing 50% by 2050. This transition is imperative for diminishing dependence on fossil fuels and mitigating GHG emissions. Furthermore, the mitigation analysis conducted through the LEAP model denotes that Ghana possesses considerable potential to curtail its GHG emissions by embracing low-emission technologies and policies. The mitigation and policy scenario could culminate in a reduction of approximately 30% in CO_2 emissions from the power sector by 2050 compared to the BAU scenario. This decline is ascribed to the heightened deployment of renewable energy sources and the implementation of energy efficiency measures, collectively contributing to a more sustainable energy framework. The findings indicate that investments in solar, wind, and biomass energy could markedly bolster energy security while fostering environmental sustainability.

6.1.2 Ghana's Energy Sources and Their Impact on CO_2 Emissions

Over the past two decades, Ghana has experienced a notable increase in greenhouse gas emissions, with levels reaching 59.8 million tons of carbon dioxide equivalent in 2019. The surge in emissions can be largely attributed to the energy sector, where the use of fossil fuels for transportation and electricity generation has played a significant role. Particularly, the transportation sector, especially road transport, has witnessed a marked uptick in emissions owing to the growing demand for personal vehicles and freight transportation. Both conventional and non-conventional energy sources have been impactful, with conventional sources such as crude oil and natural gas being predominant. Non-conventional sources, including hydropower, biomass, wind, and solar energy, also contribute to emissions, albeit their production and disposal processes can still have environmental implications throughout their life cycle. This is evident from the total energy demand and emissions associated with the household sector, as the sector relies heavily on biomass for basic activities such as cooking. While renewable energy sources generally have lower emissions compared to fossil fuels, it is essential to consider their full life cycle emissions. The influence of non-conventional energy sources is shaping the trends in greenhouse gas emissions, establishing a direct connection that affects the environment.

6.1.3 Implications of Low-Emission Energy Scenarios on Ghana's Energy Security

The findings of the study project a steady increase in energy demand between 2010 and 2050, driven by economic and population growth and highlight that household energy demand is expected to dominate, followed by transport, industry, and commerce. With a linear relationship between energy demand and greenhouse gas emissions, the total emissions from key energy demand sectors are also projected to increase. Consequently, the study suggests a shift towards low-carbon-intensive energy, though there are discrepancies between the study's data and official reports, indicating the need for a thorough review to improve the reliability of the findings. As such, the transition to low-emission energy scenarios in Ghana holds significant implications for the country's energy security, which pertains to the reliable availability of energy resources at an affordable price. Presently, the country relies heavily on fossil fuels, particularly thermal power generated from natural gas and crude oil. The results from both the baseline and mitigation and policy scenario including findings from literature suggest that transitioning to low emission requires the integration of renewable energy sources such as solar, wind, and hydropower.

6.1.3.1 Reliability

The low-emission (Mitigation) scenario, compared with the Business-As-Usual (BAU) pathway, projects a substantial transformation of Ghana's energy mix characterised by increased integration of renewable energy technologies, that is, solar photovoltaic (PV), wind, and distributed mini-grids, that cumulatively are targeted to reach 50% of installed capacity by 2050. This transition enhances the diversification of energy supply sources, mitigating over-reliance on hydropower and fossil fuel imports, which historically have contributed to frequent system outages and supply disruptions. However, variable renewable energy (VRE) induces challenges for grid management and requires investment in complementary technologies such as energy storage and demand response to maintain system stability. The mitigation scenario's inclusion of advanced grid technologies and energy efficiency measures improves supply reliability, thus contributing positively to Ghana's energy security framework.

6.1.3.2 Affordability

Affordability remains a central concern, particularly for vulnerable urban and rural populations. The Mitigation scenario, while increasing renewable shares, forecasts a moderated growth in total energy demand. The model anticipates that decentralised renewable systems will lower long-term energy costs for rural households, improving access with off-grid solutions where grid extension is economically unviable. The scenario also assumes phased reductions in fossil fuel subsidies and implementation of targeted tariff structures, enabling gradual affordability improvements aligned with cleaner energy use. Notwithstanding, short-term financial and infrastructural constraints could limit immediate widespread affordability gains, necessitating supportive policy instruments including subsidies for low-income consumers and mobilisation of climate.

6.1.3.3 Resilience

The resilience dimension is reinforced by the scenario's emphasis on decentralisation and diversification. Rainfall variability and climate-induced hydropower fluctuations have historically posed significant risks to Ghana's energy security (**Figure 6.1.1**). The Mitigation scenario reduces vulnerability by increasing solar and wind penetration and incorporating distributed generation, thereby decreasing dependence on highly climate-sensitive hydropower. Moreover, enhanced energy efficiency contributes indirectly by lowering peak demand and reducing systemic strain.

6.1.3.4 Broader Energy Security Implications

Together, the low-emission scenarios align Ghana's energy system with enhanced sustainability objectives while supporting the triple bottom line of energy security: reliable, affordable, and resilient supply. The study's quantitative findings indicate a potential 27% reduction in carbon emissions by 2050 compared to BAU, supporting a low-carbon transition. This also complements national goals embedded in the National Energy Transition Framework and Paris Agreement commitments, further linking energy security with climate stability.

The evidence suggests that low-emission futures can contribute positively to economic stability by mitigating risks of energy price volatility and supply interruptions. However, the transition requires coordinated policy and investment in infrastructure, regulatory frameworks to manage VRE integration, and social programs to ensure equitable access, especially for rural and marginalised communities.

6.2 Recommendations

Drawing from the principal findings, the study advances a series of recommendations aimed at steering Ghana's energy trajectory. These encompass fortifying renewable energy policies, instituting demand-side management strategies, allocating resources for energy infrastructure, and advocating for energy efficiency standards. The study highlights the importance of a robust policy framework that supports the transition to a low-carbon energy system, ensuring both energy security and affordability. The recommendations are structured into short-term (urgent), medium-term, and long-term priorities, and include realistic implementation pathways and funding sources.

6.2.1 Recommendations for Policy and Decisionmakers

The study indicates a projected increase in energy demand from the base year to the end year, which is expected to impact the proliferation of greenhouse gas emissions. To address the challenges identified in the energy sector and capitalise on the opportunities presented by renewable energy and energy efficiency measures, the following recommendations are crucial:

Priority 1: Immediate Actions (Short-Term, 1-3 years)

Key Actors: Ministry of Energy, Energy Commission, EPA, Local Government

1. Efforts to encourage energy efficiency and conservation among consumers, through demand-side management (DSM) strategies such as public awareness campaigns and financial incentives for energy-efficient appliances, should be strengthened and promoted.
2. It is essential to enhance existing renewable energy policies to facilitate the development and integration of renewable energy sources such as wind, solar, wave, and biomass into the demand side of the national energy mix. This requires revising the current target of scaling up renewable energy to 10% by 2030 to 30% by 2030 and reaching approximately 50% by 2050. Efforts to incentivise individuals and organisations through the Sustainable Use of Natural Resources and Energy Finance (SUNREF) program should be strengthened and made more accessible to the general public in Ghana. While measures are being taken to expand the electricity grid to reach non-electrified areas through the rural electrification programme, there is minimal effort to harness energy from renewable sources in these areas. It is imperative to fund and install at least 200 new solar or hybrid mini-grids for rural communities and peri-urban areas (target: >150,000 new households reached by 2035). Leverage concessional finance from the Green Climate Fund and the Ghana Climate Innovation Centre.
3. Enhance monitoring and enforcement powers of the EPA and Energy Commission, especially for grid operators and urban commercial sectors, to tackle non-compliance with building codes, unlawful connections, and emissions caps.
4. Household cooking activities significantly contribute to energy demand and emissions, mainly because of the widespread use of wood and charcoal as primary fuels. Promoting

the use of clean cooking fuels like LPG in both urban and rural households, alongside making new, improved, and efficient cookstoves more affordable, are crucial steps to lower emissions. It is vital to launch coordinated nationwide campaigns involving civil society and media to encourage energy-saving habits and the adoption of clean cooking technologies; aim for a minimum 20% increase in LPG and improved cookstove use by 2030.

5. The government of Ghana needs to secure climate finance (e.g., GCF, international development partners) to co-finance the roll-out of these urgent initiatives. Fast-track public procurement reforms to enable new energy projects.

Priority 2: Medium-Term Actions (3 -7 years)

Key Actors: Ministry of Energy, VRA/ECG, Private Sector, Local Assemblies, Development Finance Institutions

1. The Electric Vehicle Initiative (EVI) should be strengthened and incentivised to promote the adoption of electric and energy-efficient vehicles, reducing reliance on fossil fuels and lowering greenhouse gas emissions.
2. Invest in building the capacities of technicians, engineers, and policy staff through partnerships with technical/vocational institutes and universities, in support of the changing energy landscape.

Priority 3: Long-Term "Transformative" Actions (7 -15+ years)

Key Actors: Government of Ghana, Ministry of Finance, Private Consortia, International Partners

1. Implementing and properly regulating carbon pricing mechanisms, such as a carbon tax or cap-and-trade system, can provide financial incentives for emissions reduction,

encouraging industries to adopt cleaner technologies. Supporting research and development in clean energy technologies will foster innovation and enhance Ghana's energy sector competitiveness, including exploring technologies like energy storage, smart grids, and carbon capture and storage.

2. Pilot Carbon Capture, Utilisation, and Storage (CCUS) in partnership with international technology firms and Ghana's major thermal generators, to capture and store at least 100,000 tonnes CO_2 per year by 2035. R&D should be co-financed with international climate funds.
3. Commission and deliver at least 500 MW of battery or pumped hydro storage capacity by 2040. Phased implementation should focus first on grid-connected regions with high renewable potential, supported by blended finance and PPPs.
4. Expand participation in regional grids (West African Power Pool) and cross-border renewable energy trading to ensure overall system resilience and price competitiveness.

6.2.2 Recommendations for Future Research

Based on the findings and insights from the study, the following recommendations for future research must be considered to address existing knowledge gaps, enhance the understanding of Ghana's energy landscape, and inform effective policy and decision-making.

1. A future research endeavour should undertake a comprehensive assessment of the various renewable energy resources available in Ghana, encompassing solar, wind, hydro, and biomass. This evaluation should meticulously examine the technical feasibility, economic viability, and environmental impacts of deploying these resources at scale. Understanding the potential contributions of each renewable source can assist policymakers in prioritising investments and developing targeted strategies.

2. Longitudinal studies that track energy consumption patterns across different sectors (residential, commercial, industrial, and transportation) over time should be conducted regularly to yield valuable insights into the evolution of energy demand. It could facilitate the identification of trends, behavioural changes, and factors influencing energy use, thereby enabling more accurate forecasting and effective demand-side management strategies.
3. As Ghana augments its reliance on intermittent renewable energy sources, in-depth research on energy storage technologies and their integration into the energy system will be imperative. Future studies should explore the potential for various energy storage solutions, such as batteries and pumped hydro storage, to enhance grid stability and reliability while accommodating a higher share of renewables.
4. Research should delve into the socio-economic impacts of transitioning to a low-emission energy system in Ghana. This entails analysing job creation, economic growth, and the effects on vulnerable communities. Understanding these impacts will be critical for designing inclusive energy policies that promote social equity and economic development.
5. A forthcoming research agenda should centre on the intersection of energy planning and climate resilience. Studies could investigate how Ghana's energy infrastructure can be designed or retrofitted to withstand climate-related disruptions, such as extreme weather events. This research will be instrumental in ensuring that energy systems remain reliable and resilient in the face of climate change.
6. Given the interconnected nature of energy systems in West Africa, future research should examine opportunities for regional cooperation in energy generation and distribution. Collaborative studies could assess the potential for cross-border electricity trade, shared

renewable energy projects, and joint investment in infrastructure to enhance energy security and reduce costs.

7. Understanding public perception and stakeholder attitudes toward renewable energy and energy efficiency initiatives is essential for successful policy implementation. Future research should explore the factors influencing public acceptance of renewable energy projects and the role of stakeholder engagement in the decision-making process.
8. Research should scrutinise the role of technology and innovation in enhancing the efficiency and sustainability of Ghana's energy sector. This includes investigating emerging technologies, such as smart grids, demand response systems, and advanced energy management solutions, that can facilitate the transition to a low-emission energy future.

6.2.2.1 Potential Barriers to Executing Proposed Recommendations"

1. The entrenched position of fossil fuel sectors and related stakeholders contributes to policy resistance, especially concerning subsidy removal and fiscal incentives for renewables. Political will is sometimes tempered by concerns over social impact (e.g., rising fuel prices) and job security in conventional energy sectors.
2. Fragmentation between ministries and agencies (e.g., Energy, Finance, Environment) often leads to delays and diluted policy implementation. Overlapping regulatory responsibilities and a lack of a single coordinating authority can stymie effective decision-making.
3. Ghana's public debt, which surpassed 90% of GDP in 2023, sharply reduced fiscal space for new infrastructure investment. This makes it challenging for the government to finance large capital projects in renewables or grid modernisation.

4. Many renewable projects (especially storage, wind, and grid-scale solar) face high initial costs. Small and medium-sized enterprises and rural communities experience limited access to affordable financing due to stringent collateral and credit requirements.
5. Outdated transmission/distribution systems, high technical losses (exceeding 30%), and limited capacity to absorb intermittent renewable power make grid integration a major technical and institutional challenge.

6.2.2.2 Implementation Pathways and Solutions

1. Consolidate and clarify agency mandates under a high-level National Energy Transition Taskforce.
2. Prioritize clear timelines for subsidy reform, regulatory streamlining, and enforcement (e.g., full implementation of net metering, national building codes).
3. Scale up blended finance models (e.g., combining soft loans or grants from multilateral banks and climate funds with private investment) to reduce risk and attract commercial capital.
4. Issue green bonds and explore debt-for-climate swaps as innovative options to unlock new funding.
5. Streamline capacity-building to improve government readiness for GCF and CIF applications; prioritize projects likely to attract concessional funding through clear climate and social benefits.
6. Strengthen legal and regulatory frameworks for PPPs (e.g., enforce Public Private Partnership Act, 2020).

7. Structure deals to attract international consortia, leveraging PPPs for new grid infrastructure, utility-scale renewable plants, and long-term O&M contracts in rural electrification.
8. Develop transparent risk-sharing and tariff mechanisms to ensure bankability while maintaining affordability for end-users.
9. Prioritise low-cost, high-impact interventions: enforcement of efficiency standards, targeted loss reduction, behaviour change campaigns (to boost public support and reduce losses).
10. Set clear, staged targets for technology scale-up (e.g., mini-grids, captive solar rooftop roll-out) so progress is measurable alongside broader reforms.

6.3 Conclusion

6.3.1 Overview and Summary

The adverse effects of climate change on the global environment are profound, affecting ecosystems, weather patterns, and human well-being. In Ghana, where agriculture plays a crucial role in sustaining the population, the impact of climate change on crop yields and water availability is particularly alarming. Farmers are confronted with issues such as reduced productivity, heightened pest attacks, and water scarcity, which jeopardise food security and worsen poverty levels. Human activities, such as deforestation, industrialisation, and the combustion of fossil fuels, release greenhouse gases into the atmosphere, contributing to the phenomenon of global warming.

The energy sector holds significant sway in both exacerbating and ameliorating climate change. For developing countries like Ghana, achieving a balance between industrialisation, economic expansion, and the transition to cleaner, sustainable energy sources is crucial. Ghana's energy mix, which encompasses hydroelectric, fossil fuel, and renewables, is critical for meeting escalating energy needs while curbing greenhouse gas emissions. However, the predominant use of thermal power generation by the majority of the population significantly contributes to carbon emissions, exacerbating the effects of climate change. According to the 2021 Greenhouse Gas Emission Report, the energy sector is the largest emitter in Ghana, accounting for 45.7% of emissions, with agriculture, forestry, and other land use contributing 44.6%. This underscores the pressing need to focus on energy consumption and production as a central area for reducing carbon emissions.

Ghana's energy sector plays a significant role in its economy, but it is heavily reliant on conventional sources, particularly fossil fuels. This overdependence poses risks to economic growth and development. Ghana's electricity generation disproportionately favours traditional sources, leading to financial challenges. The country currently has an installed capacity of 4,132MW for existing plants, with 38% coming from hydro, 61% from thermal, and less than 1% from solar energy. Despite the abundant renewable energy resources, renewable energy currently only contributes 1% to the energy mix.

The energy sector currently grapples with challenges arising from the absence of comprehensive long-term forecasting and planning tools, which have resulted in an unreliable and unsustainable energy system and associated GHG emissions. The study aimed to tackle this challenge by addressing the research questions and objectives outlined. It utilised a quantitative research design, employing the Low Emission Analysis Platform (LEAP) to analyse data based on two scenarios: the baseline scenario and the mitigation and policy scenario.

The results obtained from the study reveal that demand from the energy sector accounts for approximately one-third of the total energy supply, with the household sector dominating this account, followed by the transport, industry, and commercial sectors. Both energy demand and supply exhibited a linear increase from the base year (2010) through the first scenario year (2011) to the end year (2050). Over the period, associated emissions also experienced linear growth; however, the total emissions resulting from excessive energy demand in the mitigation and policy scenario were lower than the baseline scenario. **Figure 5.8.1** gives a graphical presentation of the trend in supply, demand and emissions over the years. The mitigation and policy scenario considered energy efficiency and various policy measures for the analysis, resulting in variations in total energy demand, supply, and emissions. These observations provide a comprehensive understanding of energy sector demands and potential pathways to mitigate high energy demand and reduce greenhouse gas (GHG) emissions.

There were disparities in the study's results and data from national reports due to some anomalies in the data collected and assumptions made for the various scenarios. However, based on the results, the study provides some recommendations that will guide further research and policymakers to pursue e low-carbon economy and promote sustainable development.

Summary of Recommendations

In order to enhance Ghana's energy sector, it is essential to reconsider the current renewable energy target, aiming for 50% by 2030 and 65% by 2050 instead of the existing goal of 30% by 2030. Strengthening the Sustainable Use of Natural Resources and Energy Finance (SUNREF) program and implementing demand-side management strategies, such as public awareness campaigns and financial incentives for energy-efficient appliances, are crucial steps. Investing in energy infrastructure is also vital. This includes upgrading existing power plants, enhancing energy efficiency, and reducing emissions in rural areas. Furthermore, promoting clean cooking fuel like

LPG and making cookstoves more affordable is imperative for reducing emissions, particularly in rural households. To encourage the adoption of electric and energy-efficient vehicles and reduce reliance on fossil fuels, it is important to bolster and incentivise the Electric Vehicle Initiative (EVI). Implementing carbon pricing mechanisms, such as a carbon tax or cap-and-trade system, can provide financial incentives for emissions reduction and encourage industries to adopt cleaner technologies. Additionally, supporting research and development in clean energy technologies, such as energy storage, smart grid systems, and carbon capture and storage, will foster innovation and enhance Ghana's energy sector competitiveness.

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Appendices

Appendix A – Household Sector

Table 1A. 1 Energy demand by fuel type for the baseline scenario at 5-year intervals from 2010 to 2050 (million GJ)

Year	Electricity	Kerosene	LPG	Wood	Charcoal	Total
2010	12.63	3.68	6.79	43.88	21.59	88.99
2015	17.01	2.94	9.82	43.75	24.31	97.83
2020	22.36	2.21	13.32	43.21	27.38	108.47
2025	28.85	1.51	17.35	42.17	30.81	120.69
2030	36.72	0.87	21.98	40.56	34.67	134.80
2035	44.67	0.64	27.38	38.26	39.00	149.95
2040	54.09	0.41	33.33	35.15	43.86	166.85
2045	65.27	0.20	40.23	31.10	49.31	186.11
2050	78.53	0.01	48.08	25.96	55.42	208.00

Table 1A. 2 Energy demand in urban households based on energy-intensive activities (million GJ)

Activity	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Cooking	29.09	34.38	42.35	53.76	69.52	90.76	118.81	155.29	202.15
Lighting	2.31	2.62	2.99	3.40	3.89	4.45	5.10	5.85	6.71
Refrigeration	3.62	4.63	5.81	7.21	8.83	10.73	12.94	15.51	18.48
Others	3.64	4.23	4.94	5.81	6.84	8.04	9.42	10.97	12.67
Total	38.66	45.86	56.09	70.18	89.08	113.98	146.26	187.61	240.01
Mitigation and policy scenario									
Cooking	29.09	33.70	39.32	46.17	54.53	64.73	77.17	92.31	110.75
Lighting	2.31	2.95	3.69	4.51	5.43	6.53	7.78	9.21	10.85

Refrigeration	3.62	4.49	5.42	6.40	7.38	8.44	9.49	10.48	11.35
Others	3.64	4.56	5.71	7.12	8.86	11.02	13.69	17.00	21.08
Total	38.66	45.70	54.13	64.19	76.21	90.72	108.13	129.00	154.02

Table 1A. 3 Energy demand from rural households based on energy-intensive activities (million GJ)

Activity	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Baseline scenario									
Electrified	20.16	28.60	39.38	53.73	73.29	90.27	112.97	142.88	181.84
Cooking	17.07	24.07	33.04	45.12	61.81	76.67	96.74	123.45	158.48
Lighting	1.28	1.90	2.65	3.56	4.67	5.41	6.28	7.30	8.50
Refrigeration	0.52	0.89	1.40	2.08	2.96	3.69	4.57	5.60	6.81
Others	1.28	1.74	2.30	2.98	3.85	4.50	5.37	6.53	8.05
Non Electrified	29.47	24.65	19.80	14.31	7.34	6.56	5.31	3.27	-
Cooking	26.15	22.11	17.99	13.19	6.87	6.22	5.09	3.17	-
Lighting	3.32	2.55	1.81	1.12	0.47	0.34	0.22	0.11	-
Total	49.62	53.25	59.18	68.04	80.62	96.83	118.28	146.15	181.84
Mitigation and policy scenario									
Electrified	20.16	29.14	41.78	60.63	89.18	110.69	137.87	172.02	214.68
Cooking	17.07	24.48	35.13	51.53	77.07	96.45	121.16	152.42	191.73
Lighting	1.28	1.90	2.65	3.56	4.67	5.41	6.28	7.30	8.50
Refrigeration	0.52	0.89	1.39	2.06	2.93	3.64	4.49	5.48	6.66
Others	1.28	1.88	2.61	3.48	4.52	5.19	5.95	6.81	7.80

Non Electrified	29.47	25.00	20.90	16.15	9.01	8.14	6.58	4.01	-
Cooking	26.15	22.48	19.12	15.07	8.56	7.82	6.38	3.91	-
Lighting	3.32	2.52	1.77	1.08	0.45	0.32	0.21	0.10	-
Total	49.62	54.14	62.67	76.77	98.19	118.83	144.46	176.03	214.68

Table 1A. 4 GHG emissions from urban households by activity technology ($MtCO_{2e}$)

Activity	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Cooking	0.64	0.92	1.34	1.95	2.80	3.95	5.47	7.45	10.00
LPG Stove	0.47	0.71	1.02	1.41	1.91	2.53	3.31	4.27	5.47
Wood Stoves	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.03	0.02
Charcoal Stoves	0.10	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.17
Kerosene Stoves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clean Cooking with LPG	-	0.03	0.14	0.34	0.68	1.18	1.88	2.85	4.13
Improved Cookstoves	-	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.05
Improved Charcoal Stoves	-	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.14
Improved Mud Stoves	-	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Lighting	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Kerosene lantern	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Total	0.65	0.93	1.35	1.96	2.81	3.96	5.48	7.45	10.00
Mitigation and policy scenario									
Cooking	0.64	0.88	1.20	1.59	2.09	2.72	3.50	4.47	5.67
LPG Stove	0.47	0.71	1.02	1.41	1.91	2.53	3.31	4.27	5.47
Wood Stoves	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.03	0.02
Charcoal Stoves	0.10	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.17
Kerosene Stoves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clean Cooking with LPG	-	-	-	-	-	-	-	-	-
Improved Cookstoves	-	-	-	-	-	-	-	-	-
Improved Charcoal Stoves	-	-	-	-	-	-	-	-	-
Improved Mud Stoves	-	-	-	-	-	-	-	-	-
Lighting	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-
Kerosene lantern	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-
Total	0.65	0.89	1.21	1.60	2.10	2.72	3.50	4.47	5.67

Table 1A. 5 GHG emissions from rural households by activity technology ($MtCO_{2e}$)

Branch	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Electrified	0.2	0.3	0.4	0.7	1.1	1.5	2.1	2.9	3.9
Cooking	0.2	0.3	0.4	0.6	1.0	1.5	2.0	2.8	3.9
Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non Electrified	0.5	0.4	0.3	0.3	0.1	0.1	0.1	0.1	-
Cooking	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	-
Lighting	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	-
Total	0.7	0.7	0.8	0.9	1.2	1.6	2.2	2.9	3.9
Mitigation and policy scenario									
Electrified	0.2	0.3	0.6	1.1	2.2	2.9	3.9	5.0	6.4
Cooking	0.2	0.3	0.6	1.1	2.2	2.9	3.8	5.0	6.4
Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non Electrified	0.5	0.4	0.4	0.4	0.3	0.2	0.2	0.1	-
Cooking	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.1	-
Lighting	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	-
Total	0.7	0.8	1.0	1.5	2.4	3.2	4.1	5.1	6.4

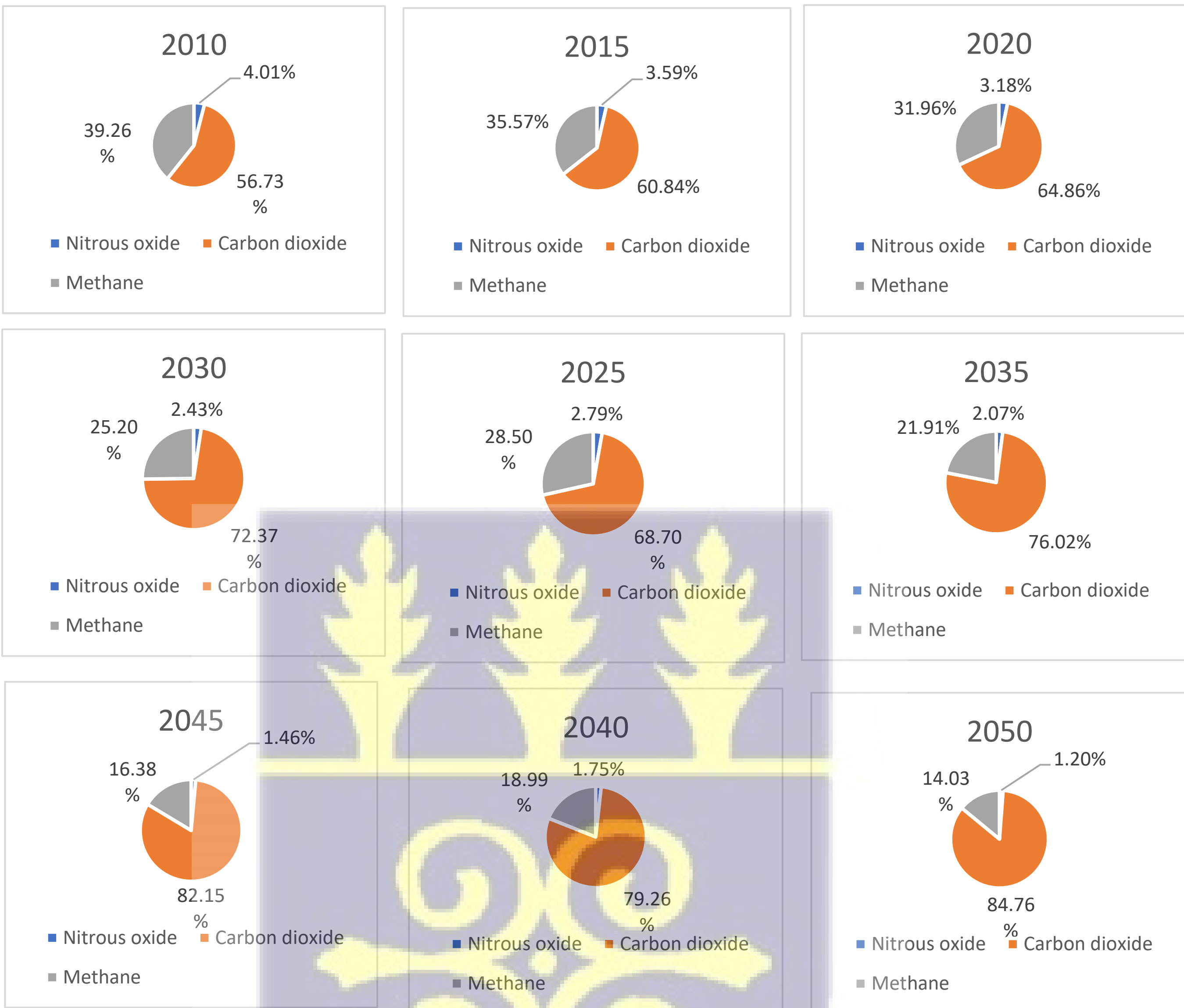

Figure 1A. 1 Trend in Emission by GHG type from 2010 to 2050

Appendix B – Industry Sector

Table 1B. 1 Energy demand from industry based on activities and fuel type (million GJ)

Activity	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Aluminium	-	0.16	0.40	0.66	0.97	1.33	1.73	2.18	2.67
Process	-	0.16	0.40	0.66	0.97	1.33	1.73	2.18	2.67
Steel and Iron	14.40	14.40	17.86	17.86	17.86	17.86	17.86	17.86	17.86
Process	14.40	14.40	17.86	17.86	17.86	17.86	17.86	17.86	17.86
Cement	1.39	1.98	2.77	2.77	2.77	2.77	2.77	2.77	2.77
Process	1.39	1.98	2.77	2.77	2.77	2.77	2.77	2.77	2.77
Other industries	16.58	20.20	24.61	29.99	36.54	44.52	54.24	66.09	80.52
Diesel	3.58	4.23	4.98	5.87	6.91	8.11	9.52	11.15	13.04
Residual Fuel Oil	0.38	0.45	0.53	0.62	0.73	0.86	1.00	1.17	1.37
LPG	0.07	0.08	0.09	0.11	0.13	0.15	0.18	0.21	0.24
Wood	2.55	3.02	3.56	4.19	4.93	5.80	6.81	7.98	9.34
Charcoal	0.05	0.06	0.07	0.08	0.09	0.11	0.12	0.14	0.16
Electricity	9.95	12.37	15.38	19.12	23.75	29.49	36.61	45.44	56.37
Total	32.37	36.74	45.64	51.28	58.14	66.48	76.60	88.90	103.82
Mitigation and policy scenario									
Aluminium	-	0.07	0.32	0.80	1.57	2.69	4.21	6.20	8.73
Process	-	0.07	0.32	0.80	1.57	2.69	4.21	6.20	8.73
Steel and Iron	14.40	14.04	16.98	16.56	16.15	15.75	15.36	14.98	14.61
Process	14.40	14.04	16.98	16.56	16.15	15.75	15.36	14.98	14.61
Cement	1.39	1.77	2.27	2.90	3.71	4.74	6.06	7.75	9.91
Process	1.39	1.77	2.27	2.90	3.71	4.74	6.06	7.75	9.91
Other industries	16.58	18.75	21.19	23.96	27.09	30.63	34.63	39.15	44.26
Diesel	3.58	3.92	4.29	4.69	5.12	5.58	6.08	6.61	7.17
Residual Fuel Oil	0.38	0.42	0.46	0.50	0.54	0.59	0.64	0.69	0.75
LPG	0.07	0.07	0.08	0.09	0.09	0.10	0.11	0.12	0.13
Wood	2.55	2.80	3.06	3.35	3.66	3.99	4.35	4.73	5.13
Charcoal	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.09
Electricity	9.95	11.48	13.25	15.27	17.61	20.29	23.37	26.91	30.98
Total	32.37	34.63	40.76	44.22	48.52	53.81	60.26	68.08	77.51

Table 1B. 2 GHG emissions from industry by activity and fuel type ($MtCO_{2e}$)

Activity	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline									
Aluminium	-	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.06
Process	-	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.06
Other industries	0.30	0.35	0.42	0.49	0.58	0.68	0.79	0.93	1.09
Diesel	0.26	0.31	0.36	0.43	0.50	0.59	0.69	0.81	0.95
Residual Fuel Oil	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.09	0.10
LPG	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Charcoal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.30	0.35	0.42	0.50	0.59	0.70	0.83	0.97	1.14
Mitigation and policy scenario									
Aluminium	-	0.00	0.00	0.01	0.02	0.04	0.06	0.10	0.15
Process	-	0.00	0.00	0.01	0.02	0.04	0.06	0.10	0.15
Other industries	0.30	0.33	0.36	0.39	0.43	0.46	0.51	0.55	0.60
Diesel	0.26	0.29	0.31	0.34	0.37	0.41	0.44	0.48	0.52
Residual Fuel Oil	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05
LPG	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Charcoal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.30	0.33	0.36	0.40	0.45	0.50	0.57	0.65	0.75

Appendix C – Transport Sector

Table 1C. 1 Energy demand from transport by mode of transport and fuel type (million GJ)

Activity	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Baseline scenario									
Passenger	39.81	55.69	58.30	60.93	63.56	65.99	67.93	69.60	71.11
Rail	0.60	0.54	0.46	0.75	1.36	2.07	2.54	2.99	3.49
Diesel	0.60	0.54	0.46	0.75	1.36	2.07	2.54	2.99	3.49
Air	-	15.48	15.93	16.39	16.86	17.35	17.85	18.36	18.89
Gasoline	-	15.48	15.93	16.39	16.86	17.35	17.85	18.36	18.89
Road	39.21	39.67	41.91	43.79	45.34	46.58	47.54	48.25	48.73
Car	29.59	31.50	34.62	37.34	39.69	41.71	43.41	44.84	46.01
Bus	9.61	8.17	7.30	6.45	5.65	4.87	4.12	3.41	2.72
Freight	29.45	30.41	33.07	38.12	45.31	53.39	59.91	66.43	73.59
Rail	2.22	2.67	3.18	5.92	10.63	16.03	19.66	23.07	26.88
Diesel	2.22	2.67	3.18	5.92	10.63	16.03	19.66	23.07	26.88
Air	0.56	0.60	0.64	0.69	0.75	0.81	0.87	0.94	1.01
Gasoline	0.56	0.60	0.64	0.69	0.75	0.81	0.87	0.94	1.01
Road	26.68	27.14	29.24	31.50	33.93	36.56	39.38	42.42	45.70
Diesel	26.68	27.14	29.24	31.50	33.93	36.56	39.38	42.42	45.70
Total	69.26	86.11	91.37	99.05	108.87	119.38	127.83	136.02	144.71
Mitigation and policy scenario									
Passenger	39.81	57.75	58.93	60.05	61.40	62.51	63.38	64.23	65.16
Rail	0.60	0.54	0.47	0.77	1.42	2.17	2.70	3.21	3.78
Diesel	0.60	0.54	0.47	0.77	1.42	2.17	2.70	3.21	3.78
Air	-	15.48	15.93	16.39	16.86	17.35	17.85	18.36	18.89
Gasoline	-	15.48	15.93	16.39	16.86	17.35	17.85	18.36	18.89
Road	39.21	41.72	42.53	42.89	43.12	42.99	42.83	42.66	42.49
Car	29.59	33.90	35.10	35.46	35.72	35.64	35.56	35.51	35.48
Bus	9.61	7.83	7.44	7.43	7.41	7.35	7.27	7.16	7.01
Freight	29.45	30.72	32.04	35.62	41.17	47.43	51.92	56.20	60.89
Rail	2.22	2.67	3.18	5.92	10.63	16.03	19.66	23.07	26.88
Diesel	2.22	2.67	3.18	5.92	10.63	16.03	19.66	23.07	26.88
Air	0.56	0.60	0.64	0.69	0.75	0.81	0.87	0.94	1.01
Gasoline	0.56	0.60	0.64	0.69	0.75	0.81	0.87	0.94	1.01
Road	26.68	27.44	28.22	29.00	29.79	30.59	31.39	32.19	33.00
Diesel	26.68	27.44	28.22	29.00	29.79	30.59	31.39	32.19	33.00
Total	69.26	88.46	90.98	95.67	102.57	109.94	115.30	120.42	126.05

Table 1C. 2 GHG emission from transport by mode of transport and fuel type ($MtCO_{2e}$)

Activity	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
				Baseline scenario					
Passenger	2.80	3.96	4.13	4.32	4.50	4.67	4.80	4.92	5.02
Rail	0.04	0.04	0.03	0.05	0.10	0.15	0.19	0.22	0.25
Diesel	0.04	0.04	0.03	0.05	0.10	0.15	0.19	0.22	0.25
Air	-	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.38
Gasoline	-	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.38
Road	2.76	2.78	2.94	3.06	3.17	3.25	3.31	3.36	3.39
Car	2.05	2.18	2.40	2.59	2.75	2.89	3.01	3.11	3.19
Bus	0.71	0.60	0.54	0.47	0.42	0.36	0.30	0.25	0.20
Freight	2.17	2.24	2.43	2.80	3.33	3.92	4.39	4.87	5.40
Rail	0.16	0.19	0.23	0.43	0.77	1.17	1.43	1.68	1.96
Diesel	0.16	0.19	0.23	0.43	0.77	1.17	1.43	1.68	1.96
Air	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07
Gasoline	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07
Road	1.96	2.00	2.15	2.32	2.50	2.69	2.90	3.12	3.36
Diesel	1.96	2.00	2.15	2.32	2.50	2.69	2.90	3.12	3.36
Total	2.17	2.24	2.43	2.80	3.33	3.92	4.39	4.87	5.40
				Mitigation and policy scenario					
Passenger	2.80	4.10	4.06	4.03	4.02	3.92	3.80	3.67	3.55
Rail	0.04	0.04	0.03	0.06	0.10	0.16	0.20	0.23	0.28
Diesel	0.04	0.04	0.03	0.06	0.10	0.16	0.20	0.23	0.28
Air	-	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.38
Gasoline	-	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.38
Road	2.76	2.93	2.86	2.77	2.68	2.49	2.30	2.10	1.90
Car	2.05	2.35	2.34	2.31	2.27	2.13	1.98	1.82	1.66
Bus	0.71	0.58	0.52	0.46	0.41	0.36	0.32	0.28	0.24
Freight	2.17	2.26	2.36	2.62	3.02	3.48	3.81	4.12	4.46
Rail	0.16	0.19	0.23	0.43	0.77	1.17	1.43	1.68	1.96
Diesel	0.16	0.19	0.23	0.43	0.77	1.17	1.43	1.68	1.96
Air	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07
Gasoline	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07
Road	1.96	2.02	2.08	2.13	2.19	2.25	2.31	2.37	2.43
Diesel	1.96	2.02	2.08	2.13	2.19	2.25	2.31	2.37	2.43
Total	4.97	6.35	6.41	6.64	7.04	7.40	7.60	7.79	8.02

Appendix D – Commercial Sector

Table 1D. 1 Energy demand from the commercial sector by activity (million GJ)

Activity	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Cooling	8.00	8.80	9.46	10.00	10.39	10.61	10.65	10.46	9.95
Ventilation	0.80	1.34	1.81	2.22	2.58	2.90	3.19	3.45	3.69
Existing cooling devices	7.20	6.77	6.27	5.70	5.04	4.25	3.31	2.17	0.74
Efficient cooling devices	-	0.69	1.39	2.08	2.77	3.46	4.15	4.84	5.53
Lighting	3.00	3.07	3.11	3.13	3.12	3.08	3.02	2.91	2.77
Daylight	0.60	0.74	0.87	1.00	1.12	1.23	1.33	1.43	1.53
Existing lighting devices	2.40	2.19	1.97	1.73	1.48	1.20	0.89	0.56	0.19
Efficient lighting devices	-	0.13	0.26	0.40	0.53	0.66	0.79	0.92	1.05
Total	11.00	11.87	12.58	13.13	13.51	13.70	13.67	13.37	12.72
Mitigation and policy scenario									
Cooling	8.00	8.80	9.46	10.00	10.39	10.61	10.65	10.46	9.95
Ventilation	0.80	1.34	1.81	2.22	2.58	2.90	3.19	3.45	3.69
Existing cooling devices	7.20	6.77	6.27	5.70	5.04	4.25	3.31	2.17	0.74
Efficient cooling devices	-	0.69	1.39	2.08	2.77	3.46	4.15	4.84	5.53
Lighting	3.00	3.07	3.11	3.13	3.12	3.08	3.02	2.91	2.77
Daylight	0.60	0.74	0.87	1.00	1.12	1.23	1.33	1.43	1.53
Existing lighting devices	2.40	2.19	1.97	1.73	1.48	1.20	0.89	0.56	0.19
Efficient lighting devices	-	0.13	0.26	0.40	0.53	0.66	0.79	0.92	1.05
Total	11.00	11.87	12.58	13.13	13.51	13.70	13.67	13.37	12.72

Appendix E – Energy Supply

Table 1E. 1 Primary energy supply by source (million GJ)

Source	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline scenario									
Crude Oil	8.9	121.9	131.5	149.3	176.9	203.0	231.0	263.9	303.4
Hydro	28.0	20.9	25.7	27.6	29.4	32.6	38.1	41.3	43.9
Solid Waste	0.0	7.5	9.3	14.9	14.6	19.9	25.1	30.6	35.7
Natural Gas	32.6	29.4	36.2	38.9	38.2	39.4	40.3	41.6	42.5
Solar	0.0	62.4	76.7	82.2	107.1	136.8	138.4	168.7	196.8
Wave	0.0	18.3	22.5	36.3	47.2	48.3	73.3	86.8	111.6
Wind	0.0	2.1	2.6	4.2	4.1	4.2	7.0	7.1	8.5
Wood	190.7	211.1	238.4	274.2	320.5	379.7	454.4	548.0	664.2
Total	260.1	473.6	542.8	627.6	738.0	863.6	1007.6	1188.0	1406.7
Mitigation and policy scenario									
Crude Oil	8.9	119.2	133.3	154.4	183.0	219.2	260.9	312.1	375.6
Hydro	28.0	21.2	25.9	29.3	29.4	32.4	38.0	41.4	46.5
Solid Waste	0.0	7.7	9.4	14.5	14.6	19.7	25.0	30.7	40.8
Natural Gas	32.6	29.9	36.6	37.9	38.1	38.9	39.6	40.7	40.8
Solar	0.0	63.4	77.4	80.0	107.1	136.0	138.0	169.2	196.8
Wave	0.0	18.6	22.8	35.3	47.2	48.0	73.0	87.1	111.6
Wind	0.0	2.1	2.6	4.0	4.1	4.1	7.0	8.6	8.5
Wood	190.7	212.5	244.0	287.7	346.8	424.9	526.3	656.1	820.5
Total	260.1	474.7	551.9	643.0	770.3	923.2	1107.9	1345.8	1641.3