GROWTH IN ENERGY DEMAND AND SUPPLY AND ITS IMPLICATIONS FOR ACHIEVING AN INCLUSIVE GREEN ECONOMY IN KENYA

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A Research Paper Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Masters of Arts in Economics of the University of Nairobi

NOVEMBER, 2020

DECLARATION

This research paper is my original work and has not been presented for the award of a degree in any other university.

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DEDICATION

This research paper is dedicated to my beloved parents Jackson Kiragu and Agnes Njoroge. Your prayers kept me going.

ACKNOWLEDGEMENTS

This journey would have been impossible without God's grace and favor. To God be the Glory.

My sincere gratitude to my dedicated supervisor Professor Richard Mulwa for providing prompt and invaluable guidance throughout development of this research paper. He believed in my potential and enthusiastically guided me through development of a concrete research paper from a mere concept. It was a great privilege to work under his supervision. I am also grateful to Dr. Michael Ndwiga for providing constructive comments on my work. To the School of Economics fraternity, thank you for the support you accorded me throughout my research journey.

I am grateful to the German Academic Exchange Service (DAAD) for sponsoring my master's studies and for granting me an opportunity to participate in Heidelberg Summer School, Germany where I was able to sharpen my research skills.

To my very supportive family, this journey could not have been satisfactorily completed without your support. Mum and dad, I sincerely appreciate your prayers, love and genuine concerns during the research period. You frequently contacted me to enquire on my progress and to encourage me. My siblings, your encouragement and motivation has gone a long way in ensuring successful completion of this research. May Almighty God bless you.

Special thanks to my friends for providing emotional support during the entire research period. On a special note I thank Ken for the keen interest shown in my research work and for providing constructive comments. You were a source of unending inspiration. Socrates, thank you for encouraging me to fully exploit my potential and for providing immense support. I am highly indebted. To my classmates, I appreciate your assistance towards the completion of this research paper. God bless you all.

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LIST OF ABBREVIATIONS

BAU	:	Business as Usual
CO_2eq	:	Carbon Dioxide Equivalent
EI	:	Energy Intensity
EIA	:	Environmental Impacts Assessments
EKC	:	Environmental Kuznets Curve
EPA	:	Environmental Protection Agency
ERC	:	Energy Regulatory Commission
FAO	:	Food and Agriculture Organization
GES	:	Green Energy Scenario
GESIP	:	Green Economy Strategy and Implementation Plan
GHGs	:	Greenhouse Gases
GWh	:	Giga Watt hour
IPCC	:	Intergovernmental Panel on Climate Change
ISS	:	Institute for Security Studies
KNBS	:	Kenya National Bureau of Statistics
KPLC	:	Kenya Power and Lighting Company
LCPDP	:	Least Cost Power Development Plan
LEAP	:	Long-range Energy Alternatives Planning System
MEF	:	Ministry of Environment and Forestry
MENR	:	Ministry of Environment and Natural Resources
MOE	:	Ministry of Energy

MOEP	:	Ministry of Energy and Petroleum
$MtCO_2eq$	:	Metric Tons Carbon Dioxide Equivalent
MW	:	Mega Watts
NAP	:	National Adaptation Plan
NCCAP	:	National Climate Change Action Plan
NDC	:	Nationally Determined Contribution
NEMA	:	National Environment Management Authority
SEI	:	Stockholm Environment Institute
SMS	:	Safe Minimum Standard
UNEP	:	United Nations Environment Programme
UNFCCC	:	United Nations Framework Convention on Climate Change

ABSTRACT

The study modeled Kenya's electricity demand and supply as well as the associated greenhouse gases emissions up to the year 2030. The study was prompted by the concern on Kenya's plan to expand the exploitation of non-renewable resources for electricity generation in order to meet the growing demand. This source has the potential of increasing electricity supply but also has potential negative environmental impact such as an increase in GHGs emissions, which is contrary to Kenya's intended low carbon development pathway. Autoregressive Distributed Lag (ARDL) and Long-range Energy Alternative Planning System (LEAP) models were used to project electricity demand for both the domestic as well as industrial and commercial sectors. Electricity demand forecasts estimated using LEAP model were found to be more comparable to the forecasts in the Least Cost Power Development Plan (LCPDP), hence, the results obtained using the LEAP model were considered as the basis for the analysis. Based on the projected electricity demand, three electricity generation scenarios: Business as Usual (BAU), Green Energy Scenario 1 (GES1), and Green Energy Scenario 2 (GES2) were developed and analyzed. Cost analysis for the different electricity generation scenarios was also done to establish the costs associated with the different energy mixes. The projected demand for the domestic sector in the year 2030 is 5,378.2 GWh, while the projected demand for the commercial and industrial sector is 14,667 GWh. GHGs emissions from electricity generation in the base year was estimated to be 112.6 MtCO2eq. However, by the year 2030, GHG emissions from electricity generation is estimated to be 192.7 MtCO2eq, 63.1 MtCO2eq, and 6.3 MtCO2eq for the BAU, GES1, and GES2 respectively. Operating and maintenance (O&M) costs are expected to be 1,807.8 million US dollars by the year 2030 under the BAU, while under GES1 and GES2, these costs are expected to be 448.4 million US dollars and 587.7 million US dollars respectively. A comparison of the three scenarios in terms of the operating and maintenance costs and associated GHGs emissions indicated that GES1 is the most realistic pathway that should be followed in order for Kenya to meet the growing electricity demand and achieve its NDC commitment, hence moving towards attainment of an inclusive green economy by significant reduction of carbon emissions.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Green economy[1] plays a major role in ensuring there is sustainable development alongside substantial poverty reduction as well as reduced climate change crisis. According to Kennet (2007), an inclusive approach towards the attainment of a green economy is one that promotes environmental quality as well as social inclusion. The state of Guyana, for instance, adopted a low carbon pathway in the year 2009 in order to move towards attainment of a green economy, by investing in the renewable energy sector especially hydro generation of electricity (Megwai, Njie, & Richards, 2016). These reforms also aimed at increasing the economic growth of the country leading to creation of green jobs. The transition towards a green economy in Kenya was initiated in January 2011 where the energy sector was identified as one of the key sectors that could lead to attainment of a green economy especially if the renewable energy was exploited in place of non-renewable energy (Kaudia, Yang & Yu, 2012; Mjimba, 2014).

In Kenya, one of the key pillars of green economy is resource use efficiency which advocates for optimal utilization of resources such that both the negative environmental impacts and costs are minimized, while maximizing productivity of these resources (MENR, 2016). Energy sector is also identified as one of the areas that can significantly contribute to resource use efficiency by ensuring that energy consumption is minimized while still maintaining the productivity levels, which will in turn lead to reduction in GHGs emissions (ibid). However, electricity transmission and distribution losses in Kenya are quite high, with a steady, consistent increase over time. In the year 2018, transmission and distribution losses stood at 2,444.5 GWh which accounted for 21.9 percent of the total electricity generated which indicates inefficiency in the sector (KNBS, 2019). According to National Climate Change Action Plan (NCCAP), transmission and distribution losses by the year 2023 should be at maximum of 14 percent.

Another pillar of green economy is social inclusivity which emphasizes on equitable participation of the society towards a green economy, where by individuals should also equitably benefit from the resulting green jobs and clean environment. Generation of electricity from renewable resources results into creation of green jobs, for example during the construction of the plants (Kurdziel,

[1] A green economy is one that is resource-efficient, has low carbon, and is socially inclusive (UNEP, 2011)

Day, Kahlen, & Schiefer, 2019). In order to achieve social inclusivity in terms of a healthy environment, Kenya's Green Economy Strategy and Implementation Plan (GESIP), suggests that Environmental Impacts Assessments (EIA) should be carried out regularly. In the year 2018, Energy sector EIA carried out were 436, which was a 1.3 percent drop from the 501 EIA done in the year 2017 (KNBS, 2019).

A green economy is also referred to as a low carbon economy, whereby use of renewable energy resources is encouraged while discouraging use of non-renewable energy resources (FAO, 2010). The primary GHG emitted through human activities is carbon dioxide, where combustion of fossil fuels, for instance in electricity generation accounts for the largest human source of carbon dioxide emissions (Ozcan, 2016). Greenhouse gases which are prioritized in the Kenya's Nationally Determined Contribution (NDC) include Carbon dioxide, Nitrous Oxide, and Methane, which have different capabilities of trapping heat, and they also stay in the atmosphere for different amount of time. In order to compare the effects different GHGs has in the atmosphere, all the GHGs are converted to carbon dioxide equivalents (CO_2eq), hence, the term carbon is normally used for all GHGs (FAO, 2010). This is done by estimating how much the gas will contribute to global warming 100 years after being emitted.

Though in different portions, each country in the globe emits GHGs, with carbon dioxide being the most common GHG accounting for roughly 75 percent of the total global emissions (EPA, 2016). Some of the factors that account for the different amount of GHGs emitted per country include population size, the efficiency of the economy and the composition of the economy, where highly industrialized countries tend to emit more GHGs, mostly attributed to the energy sector (EPA, 2016; IPCC, 2014). According to FAO (2010), the more a country substitutes use of non-renewable energy resources with renewable energy resources, for instance in generation of electricity, the lesser the GHGs emitted, implying low carbon, hence green economy.

As a country strives to achieve economic development, it should take into consideration the environmental impacts associated with it and ensure that the environment is not compromised (Mutia, 2010). Since the energy sector, especially generation and consumption of electricity from non-renewable resources accounts for substantial amount of the total GHGs emissions, expanding generation of electricity from renewable sources and ensuring energy efficiency by carrying out demand-side management of electricity would play a major role in achieving green economy

(Stafford & Faccer, 2014; Ozcan, 2016; MENR, 2017; Kurdziel, Day, Kahlen, & Schiefer, 2019). Kenya's commitment to the Paris Agreement is that by the year 2050, electricity generation will be based purely from green energy, however, development of non-renewable energy is still underway (Kurdziel, et al., 2019). With the recent discovery of minerals such as coal, natural gas and oil in Kenya, it is anticipated that their exploitation, including electricity generation, will lead to significant developments in the structure of the economy as well as negative environmental impacts. For instance, emissions from electricity generation are anticipated to grow at a very high rate such by the year 2030, electricity generation will be the greatest contributor to the GHGs emissions (MENR, 2017). It is therefore important to determine the energy mix that that will result to minimal emissions from electricity generation in order to achieve a green economy.

1.1.1 Electricity Demand in Kenya

Kenya is experiencing a steady increase in electricity demand as shown in Figure 1.2. The increase is mostly attributed to an increasing population accompanied by the ambition to achieve universal electricity access by the year 2030 (MOEP, 2016; KNBS 2019). Further, increase in overall economic growth and the implementation of some proposed projects under vision 2030 in order to become an industrialized middle-income country by the year 2030, where energy sector is identified as one of the key drivers, leads to more electricity demand (Manyara & Mading, 2012; MOEP, 2015; Longa & Zwaan, 2017). According to Mokveld & Eije (2018), electricity demand grew at an annual rate of 18.9 percent between the year 2004 to 2013, and as at the year 2015, the percentage of those connected to electricity stood at 56 percent of the total population, where 78 percent of the urban and 39 percent of the rural population was connected to electricity. In the year 2018, total electricity demand stood at 11,182 GWh which represented a 7.9 percent increase from 10,359.9 GWh in 2017 (KNBS, 2019). This increase in electricity demand necessitates generation of more electricity since inadequate electricity supply leads to power outages which have negative economic impacts such as loss of jobs, reduced investments, poor service delivery, reduced GDP, low quality of life, and inflation (Ellis, Lemma, Mutimba, & Wanyoike, 2013; Kaseke & Hosking, 2013; MOE, 2018). In the year 2013, Kenya experienced an average of approximately 6 outages each month (Pueyo, 2018).

There has been an increase in the number of consumers connected to electricity over time as indicated in Figure 1.1. Electricity consumers in Kenya are classified into four main categories:

Domestic and small commercial, commercial and industrial (medium and large), street lighting, and rural electrification, (KNBS, 2019). In 2018, domestic consumers accounted for 77 percent of the total consumers connected to electricity while rural electrification and the domestic and small commercial accounted for 20 and 3 percent respectively. Commercial and industrial (medium and large) and street lighting accounted for negligible percentage (ibid).

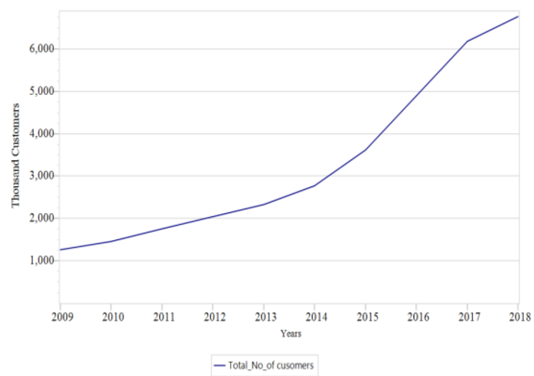

Table 1. 1: Electricity demand per Category (GWh).

Category \ Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Domestic & Small Commercial	2,058	2,200	2,471	2,569	2,866	3,274	3,255	3,316	3,528	3,666
Commercial & Industrial (Large & Medium)	3,058	3,205	3,440	3,409	3,585	3,892	4,018	4,146	4,199	4,337
Street Lighting	21	21	18	21	17	23	31	46	60	68
Rural Electrification	254	291	306	380	427	479	497	513	581	601
Transmission & Distribution Losses	1,052	1,192	1,249	1,404	1,476	1,339	1,642	1,965	1,938	2,445
Total	6,443	6,908	7,485	7,783	8,372	9,006	9,442	9,987	10,306	11,116

Figure 1.1: Total Number of Customers Connected to Electricity in Kenya.
Figure Source: Author's construction from KNBS Statistical Abstract, 2019

Table source: KNBS Statistical Abstract, 2019

In terms of amount of electricity consumed, the commercial and industrial (medium and large) accounted for 38.8 percent, domestic consumption 32.8 percent, rural electrification 5 percent, and street lighting accounted for 0.6 percent, while 21.9 percent of the total electricity generated were transmission and distribution losses (ibid). The trends in the amount of electricity consumed per category, and the transmission and distribution losses are indicated in Table 1.1 above.

1.1.2 Electricity Generation in Kenya

There is a steady increase in amount of electricity generated in Kenya as shown in Figure 1.2. Total electricity generated, inclusive of imports stood at 11,182 GWh in 2018 which represented a 7.9 percent increase from 10,359.9 GWh in 2017 (KNBS, 2019). The three main sources of electricity generation in Kenya, are geothermal, hydro, and thermal which account for 98 percent of the total electricity generated under normal hydrological conditions (Kiplagat, Wang, & Li, 2011; Taneja, 2018; MEF, 2018).

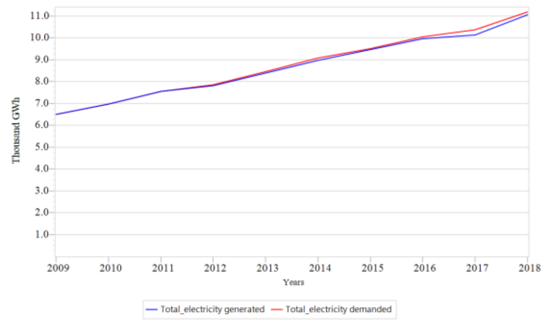

Figure 1.2: Trend in Electricity Demand and supply.
Source: Author's construction from KNBS Statistical Abstract, 2019

Table 1. 2: Generation of power by type (GWh).

Source \ Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Hydro	2,160	3,224	3,217	3,977	4,386	3,411	3,463	3,960	2,777	3,986
Thermal	2,997	2,201	2,801	2,200	2,162	2,585	1,412	1,471	2,534	1,546
Geothermal	1,293	1,442	1,444	1,516	1,781	2,917	4,521	4,484	4,756	5,128
Cogeneration	50	92	81	105	56	50	-	-	2	3
Wind	-	17	18	14	15	17	60	56	61	376
Solar	..	..	..	..	..	..	..	..	..	14
Total	6,500	6,976	7,560	7,812	8,399	8,981	9,456	9,971	10,130	11,053

Table Source: KNBS Statistical Abstract, 2019

In the past decade, electricity generation from geothermal has been on an increasing trend while the generation of electricity from thermal and hydro sources has been fluctuating over time, as shown in Table 1.2. Oil is the main non-renewable source of electricity generation in Kenya, which accounted for 14 percent of the total electricity generated in the year 2018 (KNBS, 2019). In the same period, electricity generation from renewable sources accounted for 86 percent of total electricity generated where geothermal and hydro were the largest renewable sources accounting for 46 and 37 percent of the total electricity generated, respectively (ibid). However, the hydro generation of electricity is climate-sensitive; hence, during the dry seasons, when the water levels are low, electricity generation from hydro is significantly reduced, necessitating electricity generation from GHG intensive sources such as diesel and oil (Kaseke & Hosking, 2013; Mwangi, 2014; NEMA, 2015; Laconde, 2018; Mokveld & Eije, 2018; Taneja, 2018). For example, in the year 2016, hydro and oil accounted for 40 and 15 percent of the total electricity generated respectively, however, in the year 2017, when the country experienced low rainfall, electricity generation from hydro dropped to 27 percent while generation from oil increased to 25 percent (ERC, 2018; KNBS, 2019).

According to Kurdziel, et al. (2019), changes in the electricity generation mix is inevitable as Kenya generates more electricity in order to meet the growing demand. Kenya has the potential to increase electricity generation from renewable sources such as wind and solar because of its natural endowments such as good topography, giving it good wind areas such as Marsabit, Turkana, and the Rift Valley edges (Muzee, 2011; Ongoma, 2018). The exploitation of wind for electricity generation in the Turkana area is underway, where the anticipated largest wind farm in Africa with the potential of generating 300 MW is under construction. Kenya is also endowed with hydro potential such as Lake Victoria, Rift Valley, Ewaso Nyiro North river, and Tana River basins as well as geothermal potential mainly from the Rift Valley (Kiplagat, Wang, & Li, 2011; ERC, 2018).

With the recent discovery of minerals such as coal, natural gas, and oil in Kenya, it is anticipated that their exploitation, including electricity generation, will lead to significant developments in the structure of the economy as well as negative environmental impacts such as GHG emissions (MENR, 2016). For Kenya to attain reliable electricity generation, while taking into consideration the electricity production costs, there are plans to increase the production of electricity from coal, geothermal, wind, and natural gas and reduce production from nuclear, diesel and hydro sources. In this regard, new power plants are anticipated to be commissioned by the year 2030 with the following energy mix: nuclear, geothermal, coal, wind, diesel, gas, and hydro at 19, 20, 13, 9, 9, 11, and 5 percent respectively (Mokveld & Eije, 2018). Kenya intends to start the exploitation of coal for electricity generation in the year 2024, and the target is that by the year 2030, the Lamu coal plant will generate 981.5 MW of electricity (ERC, 2018).

1.1.3 Policies on Emissions and Green Economy in Kenya

Kenya targets to follow a development pathway that will result in low carbon. In this regard, it has developed its Nationally Determined Contribution (NDC) document in its commitment towards achieving low carbon levels to contribute to the global objective of mitigating against climate change. Kenya's NDC, which was submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016, constitutes the first-ever stated commitment of Kenya towards global mitigation of climate change. It was formulated based on Kenya's historic contribution to GHG emissions in order to comply with the global commitment of reducing emissions by the year 2030, as set out in the Paris Agreement, which forms part of Kenya's law. In the NDC, Kenya targets to reduce GHG emissions by 30 percent relative to the BAU scenario of 143 $MtCO_2eq$ by the year 2030 as shown in Figure 1.3 (MENR, 2015; Kurdziel, et al., 2019). To achieve this target, two medium-term plan policies, National Climate Change Action Plan (NCCAP) and National Adaptation Plan (NAP), have been put in place. NAP discusses the adaptation strategies in response to climate change effects, for the period 2015 to 2030. NCCAP, which is reviewed after every five years, was first established in 2013, and its main legal foundation is the Climate change act, 2016. NCCAP identifies the generation of electricity from renewable sources as well as energy efficiency as key in GHG emissions reduction and a way of satisfying the increasing electricity demand. By June 2023, it is expected that additional 2,405MW of renewable energy, which includes geothermal, wind, solar, hydro, and co-generation, will be achieved, which will translate to 9.2 $MtCO_2eq$ GHG emissions reduction per year.

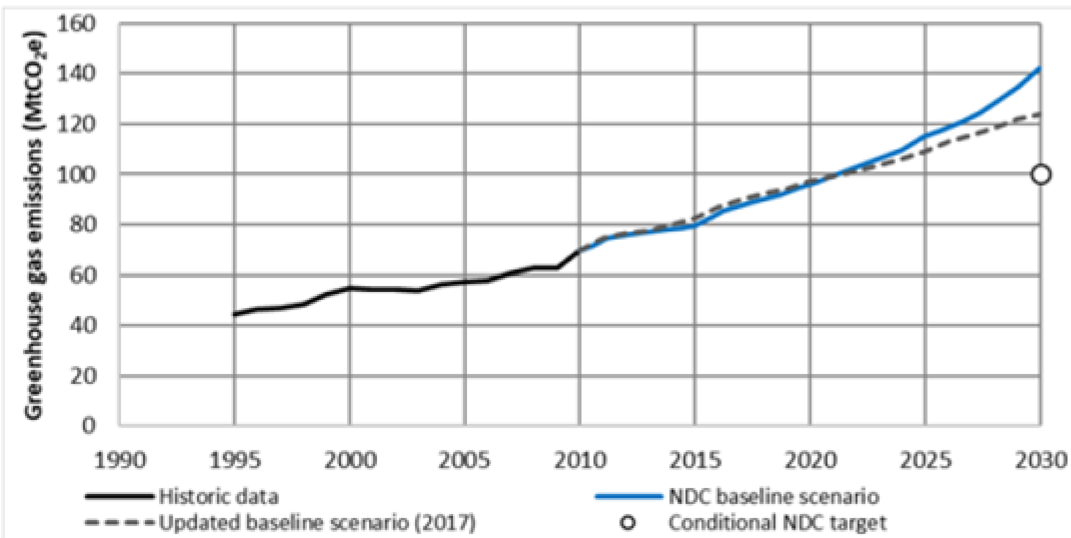

Figure 1.3: Kenya's GHGs Emissions based on NDC.

Source: Kurdziel, et al., 2019

Kenya's Green Economy Strategy and Implementation Plan (GESIP), which covers the period 2016 to 2030 and is the first one for Kenya, addresses challenges such as climate change and environmental degradation on the path towards the achievement of a green economy. This plan also plays an important role towards the attainment of the NDC commitment. The energy sector has been identified as one of the key areas which significantly contribute to GHG emissions. In 2013, the GHGs emissions from the energy sector accounted for 31.2 percent of the total GHGs emissions in Kenya (USAID, 2017). To minimize these emissions, the NDC advocates for the expansion of renewable energy such as solar, wind, and geothermal in electricity generation, as well as enhancing resources and energy efficiency in different sectors. For Kenya to achieve energy efficiency, it should come up with a target alongside an action plan towards the achievement of the set energy efficiency target. More so, substituting generation of electricity from non-renewable resources to renewable resources and increasing energy efficiency plays a major role in increasing the pace towards the attainment of a green economy.

1.2 Problem Statement

According to Vision 2030, Kenya aims at achieving an annual GDP growth rate of 10 percent per annum. In 2018, real GDP growth rate was 6.3 percent, and the growth was mainly attributed to an increase in both the manufacturing and agricultural activities (KNBS, 2019). According to MoE (2018), the real GDP is expected to continue increasing due expansion of construction, agricultural and energy sectors, as well as industrialization. Further, it is anticipated that by 2030, Kenya's population will be approximately 65 million with 33.5 percent of the population residing in the urban areas (ISS, 2018). Since demand for electricity is positively related to GDP, population size and rate of urbanization, it is expected that the projected increase in these factors will lead to increase in electricity demand. With the government working towards the attainment of universal electricity access accompanied with the ambition to become an industrialized middle-income country by the year 2030, the growth in electricity demand will require an increase in the electricity supply. However, Kenya's electricity supply, especially from hydro powered electricity generation is constrained by factors such as adverse climatic conditions leading to shortages, thus prompting the country to rely on the generation of electricity from non-renewable resources (NEMA, 2015).

Alternative sources of energy supply are therefore required to boost the current supply of electricity. This includes exploitation of non-renewable resources which has been gradually increasing. This source has the potential of increasing electricity supply but also has potential negative environmental impact such as an increase in GHGs emissions, which is contrary to Kenya's intended low carbon development pathway (SEI, 2017; Johnson, et al., 2017). Kenya's Green Economy Strategy and Implementation Plan (GESIP), for example, targets the energy sector as key in the reduction of emissions to achieve an inclusive green economy. Additionally, Kenya's NDC aims at reducing GHGs emissions by 30 percent relative to the BAU scenario by the year 2030, which translates to 42.9 $MtCO_2eq$ net emission reduction (MENR, 2015). To achieve this, emissions from electricity generation should reduce by at least 9.32 $MtCO_2eq$ relative to the BAU scenario (MEF, 2018).

With the increasing levels of electricity demand and supply and alternative sources of energy being explored, it is not clear what the levels of demand and supply will be in the year 2030, and the implications of this growth on the emission of GHGs. In turn, the level of the GHGs will determine Kenya's achievement of its commitments of the Paris Agreement as stated in the NDC. The country is therefore treading a delicate balance of meeting its electricity demand but also reducing emissions from the energy sector. Given this, we thus need to know the most efficient electricity generation energy mix that will lead to low emissions hence green economy; and the alternative viable sources of electricity generation especially from renewable sources e.g. geothermal, wind etc. to be explored if Kenya is to meet the twin goals of meeting its electricity demand and reducing emissions from electricity generation. It is against this background that this study aims to project future energy demand and supply in Kenya, and their implications on the GHGs emission reductions.

1.3 Research Questions

The following research questions will guide the study:

1. What is the projected electricity supply from different sources and demand by different sectors by the year 2030?
2. What will be the levels of greenhouse gas emissions associated with this projected electricity demand and supply?
3. Which is the most suitable energy mix that will enable Kenya achieve an inclusive green economy?

1.4 Main Objective

This study aims to assess the effects of growth in energy demand and supply on the realization of an inclusive green economy in Kenya.

1.4.1 Specific Objectives

1. To estimate electricity demand from different economic sectors and supply from different sources by the year 2030.
2. To determine the levels of greenhouse gas emissions associated with the projected electricity demand and supply by the year 2030.

3. To identify the most suitable energy mix that will enable Kenya achieve an inclusive green economy.

1.5 Justification of the study

This study will establish the most suitable energy mix in electricity generation that will enable Kenya to satisfy the growing electricity demand and supply without compromising its commitment to achieving an inclusive green economy. With such information, the government will be able to attain its commitment of achieving universal electricity access by the year 2030 with minimal negative environmental impacts. If the exploitation of non-renewable resources for electricity generation continues without giving attention to the GHG emissions associated with it, it might lead to Kenya failing to achieve its NDC commitment as well as attaining an inclusive green economy. Further, the study will significantly contribute to the scholarly work by adding to the existing empirical literature on the link between energy demand and supply and the green economy, which other scholars interested in the area can refer to.

CHAPTER TWO: LITERATURE REVIEW

2.1 Chapter Overview

This chapter discusses the theories guiding the study as well as the related studies carried out in different countries in order to give the background information required for a general understanding of the linkages between growth in energy demand and supply and the green economy. An overview of the reviewed literature is also briefly given, explaining the gap that the study intends to fill.

2.2 Theoretical Literature Review

Three theories have been reviewed in this section. Energy demand theory explaining the drivers for the demand for energy, theory of externalities which explains the link between generation of electricity and the environmental impacts in terms of emissions, and the decision theory which discusses how the optimal choice of the electricity generation mix is made based on the levels of emissions associated with the different options.

2.2.1 Energy Demand Theory

According to Evans & Hunt (2009), energy facilitates production of goods and services by providing essential inputs such as heating and lighting to households and firms, thus, demand for energy is a derived demand. The main determinant of energy consumption is economic development, which affect the energy intensity. Increase in a country's GDP leads to an increase in energy consumption, especially when the GDP increase is attributed to sectors that are energy intensive such as the industry sector (ibid).

Energy intensity (EI) is defined as total primary energy requirement per GDP, and is an efficiency parameter used to indicate the relationship between energy and economics, where lower energy intensity implies higher efficiency (Ozcan, 2016). Just like the Environmental Kuznets Curve (EKC) which shows the relationship between economic growth and emissions level, the relationship between energy intensity and economic development follows an inverted U-shaped path as shown in Figure 2.1 (Evans & Hunt, 2009; Nyangena, Senelwa, & Igesa, 2019). This is because as economies grow, they move from agricultural activities to industrial production and at the higher stage of development, they become more service oriented. As the country transition from reliance on agriculture to industrialization, more energy is consumed in industries leading to increase in energy intensity. As the economy continues to grow and become more service oriented, less energy input is required leading to decline in energy intensity, hence the inverted U-shape.

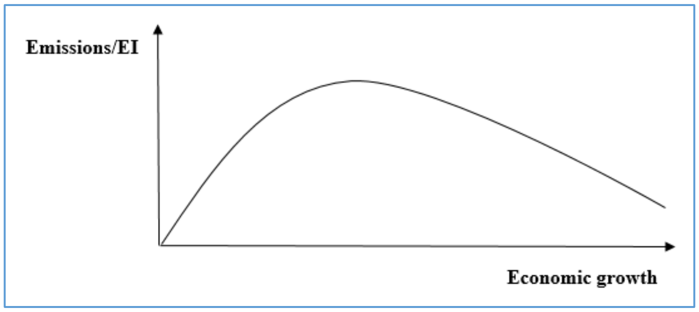

Figure 2.1: Relationship between Economic Growth, Energy Intensity, and Emissions Levels.
Source: Author's construction based on Evans & Hunt, 2009; Nyangena, et al., 2019

Other determinants of market demand for energy include income, price of energy and demographic factors such as urbanization and population growth rates (Mirjat, et al., 2018). Total energy demand is the summation of all sectors energy consumption amounts.

2.2.2 Theory of Externalities

An externality occurs when activity of an economic agent affects the utility of another agent either positively or negatively and no compensation is made, resulting into market failure (Hackett, 2006). Externalities are classified as either positive or negative depending on the effect they cause. Negative externalities occur when activity of one agent negatively affects another agent, hence reducing their level of utility, while positive externalities occur as a result of activity of one agent leading to positive effects to another agent hence increasing their utility (ibid). Further, externalities can also be classified depending on the economic activity they originate from and where the impact is experienced. Given production and consumption as the two economic activities, GHGs emissions from generation of electricity can be classified as production-consumption externality since the negative externality originates from production of electricity and it adversely affects the individuals in the society in a manner that is non-rival and non-excludable (Perman, Ma, McGilvray, & Common, 2003).

2.2.3 Decision Theory

When possible outcomes relevant to decisions are listed, but are not accompanied with probabilities, the decisions are said to be done under uncertainty and the approach adopted in choosing the most optimal outcome is called decision theory, which is an extension of game theory (Perman, Ma, Common, Maddison, & McGilvray, 2011). When the decision maker is faced with such a situation, there are four decision rules that are available for them: maximin, maximax, minimax regret rule, and assignment of subjective probabilities. Assume two strategies (1 and 2) each with two possible outcomes (X and Y) and accompanying payoffs as shown in Table 2.1. From the matrix of payoffs, a decision maker can take any of the four available decisions.

Table 2. 1: Payoff matrix for two possible decisions with two possible outcomes.

Strategy/Outcome	**Outcome X**	**Outcome Y**
Strategy 1	**120**	**10**
Strategy 2	**100**	**200**

Source: Author's computation from Perman, et al., 2011

Under maximin rule, the decision that is selected is the one that maximizes the minimum payoff possible from the outcomes. The minimum payoff for strategy 1 is 10, while that for strategy 2 is 100, hence, strategy 2 is selected as the optimum decision. The maximax rule aims at maximizing the maximum payoff possible from the outcomes. The maximum payoff for strategy 1 is 120, while that for strategy 2 is 200, hence, strategy 2 is selected as the optimum decision. The main challenge in both of these rules is that most of the information contained in the payoff matrix is ignored and this can lead to misinformed decision. The minimax regret rule entails generation of a regret matrix, which is done by identifying the highest payoff for each possible outcome and then representing the other payoffs as deviations from it, as shown in Table 2.2.

Table 2. 2: Regret Matrix.

Strategy/Outcome	Outcome X	Outcome Y
Strategy 1	**0**	**190**
Strategy 2	**20**	**0**

Source: Author's computation from Perman, et al., 2011

Each strategy of the regret matrix is then analyzed and the highest possible regret for each row noted. The minimax rule is then applied and the strategy with the minimum possible regret is chosen. The maximum regret for strategy 1 is 190 while for that for strategy 2 is 20, hence, strategy 2 is chosen since it has the minimum regret. Finally, assignment of subjective probabilities involves averaging the payoffs for each possible strategy, and the strategy with the highest average payoff is selected. The average for strategy 1 is 65 while that for strategy 2 is 150, hence strategy 2 is selected as the optimum decision since it has the highest payoff average.

However, in most of the instances while making decisions on environmental problems, radical uncertainty is experienced where by decision makers are not able to list all the possible outcomes of a decision. In such a situation, the concept of safe minimum standard (SMS) is applied while making the decision on the optimal choice. Under SMS, which acts as a precautionary principle, the optimal decision is considered to be one that results into elimination of any pollution that is deemed to lead to negative and irreversible environmental impact as well as have negative effects on resource systems. Hence, in making decision on policies which could lead to negative environmental impacts, and under radical uncertainty, the decision makers opt to be cautious, thus the SMS approach is preferred. The SMS approach can also be modified to include cost analysis whereby the optimal decision should not lead to the country incurring excessive costs (Perman, et al., 2003).

2.3 Empirical Literature Review

A number of studies have been done on electricity demand and supply, and also on greenhouse gas emissions. In India, Kale & Pohekar (2014) carried out a scenario analysis for electricity demand and supply for the Maharashtra state for the period 2012 to 2030. Holt's Exponential Smoothing method was used to estimate electricity demand, while estimation for electricity supply as well as the associated GHGs emissions and costs by the year 2030 was done using LEAP. In their analysis, three scenarios were developed: Business as usual (BAU), energy conservation (EU) and renewable energy (REN). Under the BAU scenario, the underlying assumption was that future trends will follow the past trends while in the EU and REN scenarios, different assumptions representing possible future trends were used. The REN scenario had the least GHGs emissions, followed by the EC scenario while the BAU scenario had the most GHGs emissions, with carbon dioxide being the main GHG emitted. Further, the REN scenario was found to be more economical compared to both EU and BAU scenarios since it had the least total costs. Due to these desirable qualities of the REN scenario, it was concluded to be the most desirable option that should be implemented in Maharashtra state.

Ozcan (2016), estimated the levels of GHGs emissions from electricity generation in Turkey for the period 2013 to 2017. The GHGs associated with generation of electricity from different sources were calculated based on the average life cycle of the GHGs emissions. Two scenarios, one with low plants progress rate and the other with relatively higher plant progress rates were analyzed, where by the results indicated 53 and 47 percent increase in GHGs emissions respectively. The study concluded that in order to achieve a reduction in GHGs emissions, electricity generation from non-renewable resources should be substituted with renewable resources.

A study investigating the costs of energy and associated GHGs emissions in both water and electricity sectors in Abu Dhabi was carried out by Kumar (2015). Eleven scenarios, among them business as usual, nuclear and renewable energy scenarios, were developed and analyzed using LEAP for the period 2005 to 2030. The renewable energy scenario was found to be the most expensive while the nuclear scenario was the most effective in terms of GHGs emissions reduction. The conclusion was that in order to achieve the twin goal of GHGs reduction and energy security in Abu Dhabi, energy efficiency measures should be put in place.

Ouedraogo (2017), modelled sustainable long-term electricity supply and demand in Africa. Four regional power pools, namely the West African Power Pool (WAPP), Central Africa Power Pool (CAPP), Southern Africa Power Pool (SAPP) and Eastern Africa Power Pool (EAPP) were analyzed for the period 2015 to 2040. Four scenarios were formulated and analyzed using LEAP to assess the tradeoff between the energy resource diversity, electricity generation mixes, and the associated GHGs emissions. Business as usual scenario (BAU) was formulated using both the national and regional energy master plans, demand side efficiency scenario and the supply side efficiency scenario were developed based on proposed energy efficiency measures while the underlying assumption in the renewable energy scenario was that any additional capacities in the electricity generation would be from renewable resources only. The findings were that regardless of the path followed, GHGs emissions would increase by the year 2040 due to increased electricity generation in order to meet the growing demand, which was estimated to be four times the base year demand under the BAU scenario. Biomass might comprise the highest percentage of the renewable energy exploited in these regions leading to increase in GHGs emitted. The most sustainable electricity generation path would be combining both the demand and supply side energy efficiency measures.

Timmerberg, Sanna, Kaltschmitt, & Finkbeiner (2019) did a study on renewable electricity targets by the year 2030 in selected Middle East and North Africa (MENA) countries with a focus on the associated GHGs emissions, generation costs, resources available for exploitation, and the performance based on the commitment to the Paris Agreement. MENA countries targets to attain 13 to 52 percent electricity generation from renewable resources by the year 2030. The GHGs emissions were calculated using the carbon footprint approach which is based on the global warming potentials of the different GHGs. The results indicated that generation of electricity from renewable resources is cheaper compared to non-renewable resources. Further, if the renewable electricity targets set are attained by the year 2030, there will be 14 to 25 percent reduction in GHGs emitted. However, majority of the MENA countries might not meet their renewable electricity targets by the year 2030. More so, even if the set renewable electricity targets in the MENA countries are met, these countries would still not meet their emissions reduction targets as outlined in the Paris Agreement. Therefore, more stringent GHGs mitigation policies, such as reviewing the current renewable electricity targets, would be necessary in order to meet their GHGs reduction commitment to the Paris Agreement.

In Nigeria, a scenario analysis on electricity demand and supply was carried out by Ibrahim & Kirkil (2018), for period 2010 to 2040. Three scenarios were developed: Business as usual (BAU), renewable energy (REN) and energy conservation (EU). Under the BAU scenario, the underlying assumption was that future trends would follow the past trends. EU scenario was formulated based on the assumption that the energy efficiency policies of the country would be fully implemented in the future. The basis for the REN scenario formulation was the country's renewable energy master plan, and the main assumption in this scenario was that only renewable energy power plants would be introduced in future. The costs and GHGs emissions associated with each scenario were also analyzed using LEAP. The main findings were that the REN scenario had the least GHGs emissions, while the BAU scenario had the highest GHGs emissions, with carbon dioxide being the main GHG emitted. However, in terms of costs, the REN scenario was the most expensive while the EU scenario had the least costs. The conclusion was that the EU scenario was the most suitable path to be followed for Nigeria to meet the growing electricity demand.

Nyangena, Senelwa, & Igesa (2019) investigated the determinants of carbon dioxide emissions in East Africa using panel data for the period 1960 to 2014. STRIPAT model, which is a regression equation used to estimate the effects of population, affluence and technology on environmental impacts, with the amount of carbon dioxide emissions as a proxy, was used to establish the existence of Environmental Kuznets Curve (EKC) in this region. The study concluded that economic growth, urbanization and population growth led to negative environmental impacts which would compromise future growth of these economies if not addressed by formulating policies that discourage rural- urban migration while encouraging use of clean energy.

Selvakkumaran & Silveira (2019) explored the linkages between NDCs of Kenya, Ethiopia and DRC and the country's electrification goals, with a focus on electricity generation mix and the associated GHGs emissions for the period 2012 to 2030. Simple regression model was used to estimate the levels of electricity generation by the year 2030. The estimated annual growth rate of electricity generated was 8.5, 12.4 and 6.9 percent for Kenya, Ethiopia and DRC respectively. In assessing the priority given to the electricity sector in the path to attaining the set NDCs, three parameters were developed: electricity generation mix, electricity intensity and emissions intensity. Electricity diversity in Kenya was observed to increase from 52 percent in 2012 to 80 percent in 2030, with the electricity mix comprising of geothermal, wind, hydro, coal, and diesel.

This generation mix was found to increase electricity supply but at the cost of the environment, since the emissions factor from electricity generation increased almost five fold. Hence, unlike Ethiopia and DRC whose electricity generation paths were found to take into consideration of their NDC targets regarding GHGs emissions, Kenya was observed to follow an electricity generation path that is divertive from its NDC commitment.

Luo et al. (2020) modelled the future pathways for residential energy consumption and the associated GHGs emissions in Dar-es-Salaam for the period 2015 to 2050 using LEAP. Three scenarios were developed by changing the assumptions on the urbanization rates, energy consumption and future GHGs emission by 2050 rather than GHGs mitigation policies. The scenarios analyzed were sustainable growth (SSP1), BAU growth (SSP2) and fragmented growth (SSP3), each representing different combinations of urbanization rates, energy consumption and future GHGs emission. SSP1 represents 100 percent electrification by the year 2050 with zero consumption of fossil fuels and high population growth, SSP2 represented 100 percent electrification accompanied with consumption of fossils fuels and moderate population growth while SSP3 represents slow population growth with no changes in electrification levels and fossil fuels consumptions by the households. The largest driver of GHGs emissions from the residential sector was found to be consumption of electricity, where SSP1 scenario would lead to high GHGs emissions as compared to SSP2 and SSP3. The high GHGs emissions in the SSP1 scenario was majorly attributed to increased households, thus, increase in population was found to be positively related with GHGs emissions. However, when GHG mitigation policies such as ensuring that 70 percent of the energy mix used in electricity generation by 2050 is from renewable resources was analyzed, the results indicated that there would be 66 percent reduction in GHGs emissions from electricity generation.

In Kenya, an analysis of both environmental and socio-economic impacts of exploitation of renewable energy resources with a focus in wind power projects was carried out by Ongoma (2018). The area of study was Ngong Hills, where Ngong wind farm project was the subject of interest. Primary data was collected through interviews in the year 2015, which was supplemented with reviews of documents. Frequency analysis was then carried out using excel. The implementation of the project resulted to reduction in GHGs emissions by 9,941.11 tCOeq. Further, the project boosted the country’s economic development through infrastructural development and generation of green jobs both directly and indirectly. The Ngong wind farm project was thus found to significantly contribute towards the attainment of a green economy in Kenya.

Longa & Zwaan (2017) investigated the necessity for a low carbon energy policy as well as exploitation of renewable energy as key in achieving climate change mitigation ambitions in Kenya. The Times Integrated Assessment Model (TIAM), which is a linear optimization model was used to carry out the analysis for the period 2005 to 2050. The reference scenario (REF) and three climate control scenarios, among them the Paris commitment scenario (NDC) were developed based on the emissions reduction targets. The underlying assumption in the REF scenario was that after 2010, no GHGs emissions reduction policies, inclusive of use of renewable energy were put in place, while in the NDC scenario, it was assumed that by 2030, Kenya will achieve a 20 percent GHGs reduction as compared to the REF scenario, which will remain constant until 2050. The study concluded that despite the projected increase in energy demand attributed to economic growth and increase in population size, a low carbon electricity generation path can be followed even in absence of climate change mitigation targets such as the NDC. Further, if NDC target was to be achieved, exploitation of renewable energy should be timely.

2.4 Overview of Literature

In the recent past, there has been a growing interest in projecting how the energy demand and supply might evolve in the future, with focus on the environmental impacts associated with the projected development of the energy sector. While many studies examined the future pathways for electricity demand, generation, and the associated GHGs emissions, many of these focused on the energy sectors outside Kenya, and mainly used bottom up approach while forecasting energy demand (Kumar, 2015; Ibrahim & Kirkil, 2018; Luo et al., 2020). This study fills the methodological gap by forecasting sector wise electricity demand in Kenya using an econometric model (ARDL), after which the results are imputed in the Long-range Energy Alternative Planning (LEAP) system for supply side, GHGs emissions, and cost analysis.

Further, empirical literature revealed that electricity generation and consumption is expected to be on an increasing trend, which translates to an increase in GHGs emissions if mitigation policies are not set and adhered to (Timmerberg et al., 2019; Nyangena et al., 2019). Exploitation of renewable energy for electricity generation and energy conservation are among the identified optimal paths to be followed in order for countries to achieve reduced GHGs emissions. However, a gap exists in establishing the most efficient electricity generation energy mix that will lead to low emissions hence green economy in Kenya. This study therefore developed different possible renewable energy scenarios for Kenya and estimated the associated GHGs emissions and costs using LEAP, in order to determine the most optimal renewable energy mix that will lead to attainment of an inclusive green economy in Kenya.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Overview of the Chapter

This chapter explains the methodology used in order to realize the research objectives. The conceptualization of the study is provided in the first subsection, followed by the theoretical and the empirical framework in the subsequent subsections. Thereafter, the variables that were used in the analysis are described and data sources provided.

3.2 Conceptual Framework

Based on the literature, economic factors such as GDP and demographic factors such as urbanization rate and population are key drivers of energy demand. These factors are used to estimate the demand for electricity up to the year 2030 using the Autoregressive Distributed Lag (ARDL) model. The estimated demand is then imputed in the LEAP model. Energy demand analysis is the starting point of analysis in the LEAP model since the electricity generation and the GHGs emissions analysis are based on the estimated final demand levels (Kale & Pohekar, 2014; Kumar, 2015). In order to meet the projected demand levels taking into account of the possible transmission and distribution losses, three electricity generation scenarios, presenting possible future electricity generation mixes, are developed. The three scenarios are then analyzed in terms of the GHGs emissions and costs associated with them in order to determine the energy mix that will lead to the achievement of the NDC commitment as well as contribute significantly towards the attainment of a green economy in Kenya, in terms of low carbon emissions. The conceptualization of this process is shown in Figure 3.1.

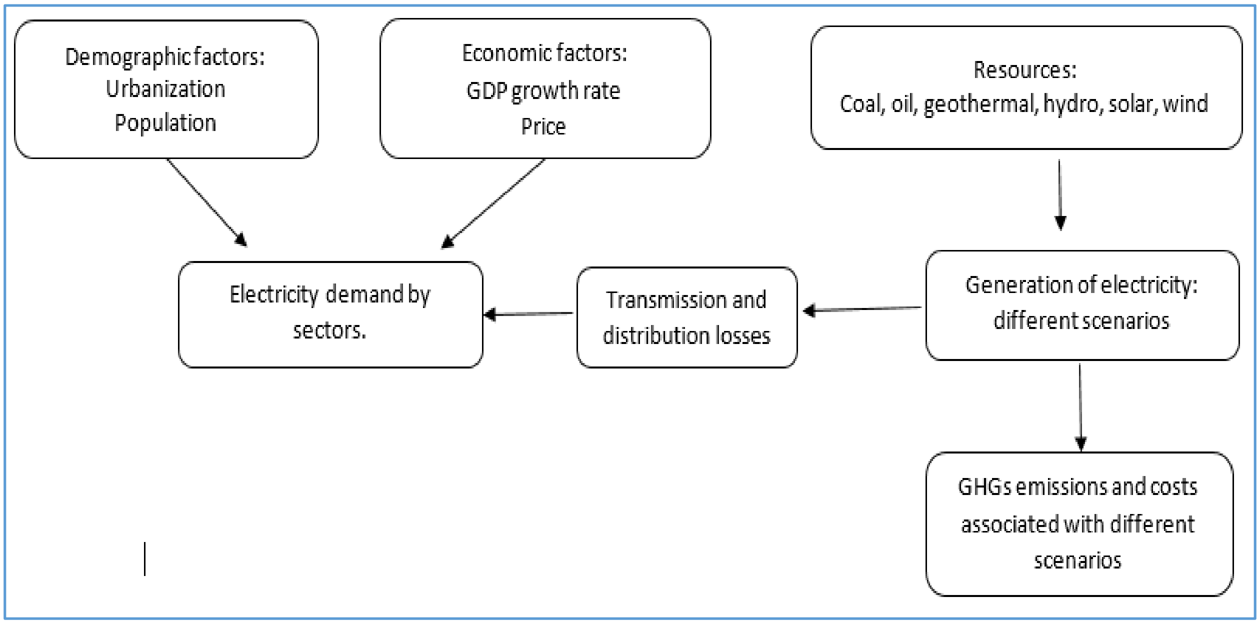

Figure 3.1: Conceptual Framework.

Source: Author's Construction, 2020

3.3 Theoretical Framework

Market demand for a commodity, which represent the total quantity of a commodity demanded by all the consumers, is influenced by factors such as price of the commodity and that of related commodities, income distribution patterns, composition and size of the population, as well as the government policies. Market demand for energy is a function economic factors such as GDP, income and price as well as demographic factors such as urbanization and population growth rates (Aziz, Mustapha, & Ismail, 2013; Mirjat, et al., 2018). The demand for electricity can be expressed as;

$$ED = f\left(E_p, Y, GDP, U, P_r\right) \tag{1}$$

Where; ED is electricity demand, E_p is price of electricity, Y is income, GDP is Gross Domestic Product, U is urbanization rate, and P_r is population growth rate. Demand for electricity is expected to be negatively related to its price and positively related to the levels of income, population size and rate of urbanization. According to Kimiyu, (1988) and Evans & Hunt (2009), the electricity demand model in Equation 1 can be specified in logarithmic form as;

$$lnED = a_0 + a_1 lnE_p + a_2 lnY + a_3 lnGDP + a_4 lnU + a_5 lnP_r + \mu \tag{2}$$

Generation of electricity (E) from inputs X_E is associated with GHG emissions which constitutes a negative externality i.e.

$$E = E(X_E, GHG), \qquad with \ \frac{\partial E}{\partial GHG} > 0 \tag{3}$$

The condition $\frac{\partial E}{\partial GHG} > 0$ implies that the level of generation of electricity, E, increases, as level of GHG emissions increases i.e. more GHGs, more electricity. The GHGs emissions negatively affect the welfare of individual i, and the emissions experienced by each individual is non-rival and non-excludable. Assuming that this utility (welfare) is a function of consumption of other goods, electricity consumed and GHGs emissions, we can express the welfare of the individual in the form a generic relationship which can be expressed as;

$$U_i = U_i(M_i, E_i, GHG), with \ \frac{\partial U_i}{\partial GHG} < 0 \tag{4}$$

Where U_i is utility (welfare) for individual i, M_i is consumption of other goods by the individual, E_i is electricity consumed by the individual and GHG is the negative externality of emissions which originated from generation of electricity. The expression $\frac{\partial U_i}{\partial GHG} < 0$ implies that increasing the levels of GHG emissions leads to lower levels of utility for individual i. Electricity generation scenarios development is therefore essential in providing guidance to the policy makers on possible future environmental impacts of different possible electricity generation pathways that a country may decide to follow. Therefore, the study analyzes three electricity generation scenarios in terms of the costs and associated emissions in order to determine the most suitable energy mix that will enable Kenya to meet the growing electricity demand, but most importantly, achieve its NDC commitment and attain an inclusive green economy by significant reduction of carbon emissions. The three electricity generation scenarios are described in details in sub section on development of electricity generation scenarios.

3.4 Empirical Framework

As stated earlier, the demand for energy is expressed as function economic factors such as GDP, income and price as well as demographic factors such as urbanization and population size (Mirjat, et al., 2018).

$$ED = f\left(E_p, Y, GDP, U, P\right) \tag{5}$$

This equation forms the basis for the empirical framework. The Autoregressive Distributed Lag (ARDL) model is commonly used in carrying out time series analysis to estimate the energy demand (Bentzen & Engsted, 2001). This is because ARDL allows for determination of long run relationship between variables, even when the series is non-stationary, by reparametrizing the series into Error Correction Model (ECM). This allows for incorporation of both the short-run and long-run relationships (Nkoro & Uko, 2016). The general form of $ARDL(p, q)$ model is specified as:

$$Y_t = \beta_0 + \beta_1 t + \sum_{i=1}^{p} \emptyset_i Y_{t-i} + \sum_{i=0}^{q} \alpha'_i X_{t-i} + \varepsilon_t, \qquad p \geq 1, q \geq 0 \tag{6}$$

Where, Y_t is the dependent variable at time t, Y_{t-i} is the lagged values of the dependent variable, X_{t-i} includes the current and lagged values of the explanatory variables, $\beta_0, \beta_1, \emptyset$ *and* α are parameters to be estimated while ε_t is the error term.

The $ARDL(p, q)$ models used in estimating the electricity demand for industrial and commercial sector as well as the domestic sector in this study are as follows:

$$ED_t^{ic} = \beta_0 + \beta_1 t + \sum\nolimits_{i=1}^{p} \emptyset_i \, ED_{t-i}^{ic} + \sum_{i=o}^{q} \delta_{1i} \, EP_{t-i}^{ic} + \sum_{i=o}^{q} \delta_{2i} GDP_{t-i}^{ic} + \sum_{i=o}^{q} \alpha_{3i} U_{t-i}^{ic} + \varepsilon_t \qquad (7a)$$

and

$$ED_t^{d} = \sigma_0 + \sigma_1 t + \sum\nolimits_{i=1}^{p} \varphi_i ED_{t-i}^{d} + \sum_{i=o}^{q} \alpha_{1i} EP_{t-i}^{d} + \sum_{i=o}^{q} \alpha_{2i} Y_{t-i}^{d} + \sum_{i=o}^{q} \alpha_{3i} U_{t-i}^{d} + \varepsilon_t \qquad (7b)$$

Equation $7a$ represents the model used in estimating electricity demand in the industrial and commercial sector while equation $7b$ represents the model used in estimating electricity demand in the domestic sector.

Where, ED is the natural logarithm of electricity demand, ED_{t-i} are the lagged values of the dependent variable, EP is the natural logarithm of the price of electricity, GDP is the natural logarithm of gross domestic product, Y is the natural logarithm of the income, U is the urbanization rate, $\beta, \emptyset, \sigma, \delta, \varphi$ and α are parameters to be estimated and ε_t is the error term. The optimal values for the lag orders p and q are determined by use of Bayesian information criterion (BIC), where the model with the lowest BIC is selected as the best estimation model. The resulting $ARDL$ models are then used to forecast sector wise electricity demand up to the year 2030.

The electricity demand projections from the ARDL model are then imputed in the Long-range Energy Alternative Planning System (LEAP), which is a widely used input-output tool with the capabilities of matching the energy demand with the energy supply, where the energy supply calculations are driven by the energy demand outcome. Further, LEAP calculates the costs as well as the associated emissions of alternative scenarios which are designed based on how the energy generation might evolve into the future. This allows for comparison of different policies in terms of environmental impacts and costs which provides the policy makers with an insight on the most appropriate pathway. The total electricity demand in the LEAP model, according to SEI (2005) is calculated as:

$$DE_{i,t} = TAL_{i,t} \times EI_{i,t} \tag{8}$$

Where, $DE_{i,t}$ is the total electricity demand for sector i at time t, TAL is the total activity level for which electricity is consumed and EI is energy intensity. *EI* is affected by the structure of the economy as well as the technological advancement of a country, and is calculated as:

$$EI_{i,t} = {}^{TEC_{i,t}}\!\big/_{GDP_{i,t}} \tag{9}$$

Where $TEC_{i,t}$is total electricity consumed in sector i at time t, and *GDPi,t* is the output of sector *i* at time *t*. For domestic consumption, energy intensity is calculated as:

$$EI = {}^{TEC}\!/_{TNC} \tag{10}$$

Where TNC is the total number of electricity consumers. Electricity supply from different sources is estimated as:

$$ES_i = EC_i + PC_i - D_i \tag{11}$$

Where *ES* is electricity supply, *EC* is existing capacity, *PC* is planned capacity additions, *D* is capacity that will be decommissioned after the life time of a plant, and *i* is the source i.e.

geothermal, hydro, wind, coal, oil and solar. Total electricity supply (*TES*) is calculated as the summation of electricity supply from different sources. i.e.

$$TES = \sum ES_i \tag{12}$$

Generation of electricity (E) from inputs X_E is associated with GHG emissions which constitutes a negative externality i.e.

$$E = E(X_E, GHG), \qquad with\ \frac{\partial E}{\partial GHG} > 0 \tag{13}$$

The condition $\frac{\partial E}{\partial GHG} > 0$ implies that the level of generation of electricity, E, increases, as level of GHG emissions increases i.e. more GHGs, more electricity. The GHGs emissions negatively affect the welfare of individual i, and the emissions experienced by each individual is non-rival and non-excludable. Assuming that this utility (welfare) is a function of consumption of other goods, electricity consumed and GHGs emissions, we can express the welfare of the individual in the form a generic relationship which can be expressed as;

$$U_i = U_i(M_i, E_i, GHG), with\ \frac{\partial U_i}{\partial GHG} < 0 \tag{14}$$

Where U_i is utility (welfare) for individual i, M_i is consumption of other goods by the individual, E_i is electricity consumed by the individual and GHG is the negative externality of emissions which originated from generation of electricity. The expression $\frac{\partial U_i}{\partial GHG} < 0$ implies that increasing the levels of GHG emissions leads to lower levels of utility for individual i. From Equations 13 and 14, increased carbon emissions imply more electricity generation, but also reduced welfare of consumers from increased GHGs and their impacts on global warming. GHGs emissions from the generation of electricity is computed as:

$$CE_{g,s} = ETP \times \frac{1}{f} \times EF \qquad (15)$$

Where $CE_{g,s}$ is the GHGs emissions from electricity generation for scenario s, ETP is the energy transformation product, $\frac{1}{f}$ is the efficiency of energy transformation and EF is the emissions factor as provided by the IPCC. The projection for electricity supply is based on the BAU scenario which is developed based on the current electricity generation policies, making the assumption that the future generation of electricity will follow the trends indicated in these policies and no new policies will be introduced in future. In addition, following the projected electricity demand, three supply side scenarios have been developed and analyzed using 2018 and 2030 as the base and end year respectively. These scenarios which include Business as Usual (BAU), Green Energy Scenario 1 (GES 1), and Green Energy Scenario 2 (GES 2) gave the projected electricity supply under different possible pathways. Supply projection is done using the installed capacity of different electricity generation plants by 2030. Historical production, process efficiency, exogenous capacity, as well as lifetime and decommissioning of each technology type (geothermal, hydro, etc.) are considered in electricity generation analysis under different scenarios. The three scenarios under consideration are described as follows:

3.4.1 Business as Usual Scenario (BAU)

The BAU represents the anticipated government's plan and is therefore developed based on the current electricity generation policies, making the assumption that the future generation of electricity will follow the trends indicated in these policies and no new policies will be introduced in future. The development of this scenario is guided by the Least Cost Power Development Plan (LCPDP). The electricity generation mix in terms of projects to be commissioned by the year 2024 as well as installed capacity by the year 2030 is as indicated in Table 3.1. Further, by the year 2030, it is assumed that there will be no electricity generation from natural gas, gas oil as well as nuclear sources.

Table 3. 1: Electricity generation by source in the BAU scenario.

Source	Projects to be commissioned by the year 2024 (MW)	Installed capacity by 2030 (MW)
Geothermal	1,188	1,898
Hydro	89	1,410.2
Wind	751	1082.1
Solar	824	914.7
Coal	981	981
Diesel	_	473.7
Cogeneration	_	28
Total	3,833	6,787.7

Source: ERC, 2018

3.4.2 Green Energy Scenario 1 (GES 1)

This scenario is developed such that electricity generation from renewable resources is encouraged while minimizing generation of electricity from nonrenewable resources. The assumption is that the renewable resources are exploited for electricity generation, without additional exploitation of nonrenewable resources such as coal.

3.4.3 Green Energy Scenario 2 (GES 2)

This scenario presents an ambitious renewable energy mix. The priority in this scenario is safeguarding the environment, thus, as non-renewable sources of electricity such as diesel nears their life span, they are phased out and substituted with addition of renewable resources such as geothermal and hydro. Further, there is no commissioning of other non-renewable sources of electricity such as coal in GES2.

In order to make conclusion on the appropriate pathway that Kenya should follow in order to achieve an inclusive green economy, a comparison of the three scenarios in terms of emissions associated with them is done. The safe minimum standard (SMS), which acts as a precautionary principle is applied while making the decision on the optimal pathway that will lead to achievement of an inclusive green economy in Kenya. Under SMS, the optimal decision is considered to be one that results into elimination of any pollution that is deemed to lead to negative environmental impact.

Further, economic viability of the scenarios is considered by comparing the three scenarios in terms of the associated fixed and variable operating and maintenance costs, where the resulting total costs of each scenario is expressed in terms of Net Present Value (NPV) which is a function of variable and fixed operating costs of the different electricity generation technologies.

3.5 Measurement of variables

Table 3. 2: Definition and measurement of variables.

Variable name	Description	Measurement
Process Efficiency	The ratio of electricity generated to energy inputs in each process.	Expressed as a percentage
Plant Lifetime	The life of a technology (geothermal, hydro etc.) from when it starts operation.	Measured in years
Exogenous Capacity	This includes existing capacity as well as planned capacity additions and retirements.	Total capacity in Megawatts (MW)
Historical Production	This variable specifies annual electricity production for a technology.	Measured in Giga-watt hour (GWh)
Emissions Factor	Average GHGs emission rate for a technology.	Measured in terms of the carbon content in a particular technology as provided by the IPCC.
Costs	This includes the capital costs as well as the fixed and variable operating costs.	Capital costs are all direct construction costs measured in million USD, fixed operating costs are incurred regardless of the amount of electricity generated and are measured as USD/Kw/Year while variable operating costs are costs incurred per unit of electricity generated and are measured in USD/MWh.

3.6 Data Sources

This study used time series data for the period 1980 to 2018, which was collected from Kenya National Bureau of Statistics (KNBS), Kenya Power and Lighting Company (KPLC) and World Bank.

3.7 Diagnostic Testing

3.7.1 Unit Root Test

This is used to test for stationarity of a series, where by if the moments (mean, variance etc.) of a series are time invariant, then the series is stationary. If a non-stationary series is estimated, it results into spurious regression, where by the regression equation indicates significant relationship between variables because of the fact that they have a common time trend when actually there is no such relation. In this study, stationarity was tested by running the Augmented Dickey-Fuller (ADF) test. Differencing was done to the non-stationary series to make them stationary.

After differencing, the regression equation only gives the short-run relationship between the variables, hence, Error Correction Term (ECT) was specified in order to incorporate both the short-run and long-run information.

3.7.2 Bounds Test

Bounds test was developed by Pesaran, Shin, and Smith (2001), and it is used for testing the existence of long-run relationship between variables. If the results show that there is no long-run relationship between variables, an ARDL model which is purely integrated of order 1, $I(1)$, can be estimated without including the Error correction (EC) term.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Chapter Overview

This chapter discusses the major findings of the study, which includes the descriptive statistics, stationarity tests, co-integration test as well as the resulting ARDL model. ARDL and LEAP models were used to forecast the electricity demand up to the year 2030. The electricity supply analysis results as well as the resulting greenhouse gas emissions associated with the different scenarios have also been discussed in this chapter.

4.2 Descriptive Statistics

The two main statistics for testing whether the data exhibits normality are kurtosis and skewness. Kurtosis measures the sharpness of a distribution relative to a standard bell curve, while skewness measures the degree of asymmetry of a distribution about its mean. A distribution which is approximately normally distributed has a skewness of between -0.5 and 0.5, and kurtosis of between -3 and 3. A comparison of median and mean also helps in determining whether the data is symmetric distributed whereby if the median and the mean are approximately equal it implies that the data is symmetric. The descriptive statistics are as shown in Table 4.1.

Table 4. 1: Descriptive Statistics.

Statistic	Variables						
	DED	**CIED**	**GDPpc**	**GDP**	**Urb**	**PriceDE**	**PriceCIE**
N	39	39	39	39	39	39	39
Mean	6.7019	7.8396	6.2806	9.6959	4.4670	1.4067	1.3247
Median	6.5945	7.8660	6.0434	9.4716	4.4375	1.8154	1.6229
SD	0.5745	0.5114	0.5660	0.8673	0.2524	1.2110	1.2224
Min	5.8960	6.8501	5.3939	8.6573	4.0525	-0.6743	-0.9203
Max	7.7646	8.6388	7.4431	11.3826	5.0508	2.8592	2.7651
Skew.	0.4521	-0.2549	0.6928	0.5679	0.7572	-0.3814	-0.4940
Kurt.	1.9892	2.1593	2.1249	1.8992	3.1833	1.7108	1.8521

DED is Domestic Electricity Consumption, **CIED** is Commercial and Industrial Electricity Consumption, **GDPpc** is Gross Domestic Product per capita, **GDP** is Gross Domestic Product, **Urb** is Urban population growth rate, **PriceDE** is the domestic electricity price, and **PriceCIE** is the commercial and industrial electricity price. All variables are in their natural log.

Source: Author’s Computation

The comparison between median and mean for all the variables indicates that the data is symmetrically distributed. This is because the mean and median are approximately equal. The skewness of prices as well as electricity demand (for both domestic and commercial and industrial) ranges between -0.5 and 0.5, implying that the data is fairly symmetrical, while skewness for GDP, GDP per capita and urbanization ranges between 0.5 and 1 implying that the data are moderately skewed to the right. Kurtosis of all variables, except urbanization, ranges between -3 and 3, implying approximately normal distribution.

4.3 Stationarity Test

In order to ensure that the residuals are not serially correlated, an optimal lag length was selected before running the unit root tests. Optimal lag selection was determined by use of Schwarz-Bayesian Information Criteria (SBIC), after which the Augmented Dickey Fuller (ADF) test was run to determine whether the series is stationary in order to avoid the problem of spurious regression. The results of the ADF tests is as shown in Table 4.2.

Table 4. 2: ADF unit root test.

Variable	Lags	Constant but no trend	Constant and trend	Comment
DED	1	0.787	-2.300	Non Stationary
D. DED	0	-5.971*	-6.216*	I(1)
CIED	2	-1.357	-2.697	Non Stationary
D. CIED	1	-5.722*	-5.790*	I(1)
GDPpc	1	0.257	-2.105	Non Stationary
D. GDPpc	0	-4.301*	-4.649*	I(1)
GDP	1	0.661	-2.165	Non Stationary
D. GDP	0	-4.374*	-4.651*	I(1)
Urb	1	-1.899	-2.424	Non Stationary
D. Urb	0	-6.404*	-6.320*	I(1)
PriceCIE	1	-1.707	-1.686	Non Stationary
D. PriceCIE	0	-6.709*	-6.876*	I(1)
PriceDE	1	-1.859	-1.421	Non Stationary
D. PriceDE	0	-3.522**	-3.866**	I(1)

*, ** indicates rejection of the null hypothesis of non-stationarity at 1% and 5% significance levels respectively.

Source: Author's Computation

All the variables are non-stationary in their levels, but after taking the first difference, they become stationary, implying that all variables are integrated of order one, that is I(1).

4.4 ARDL Regressions

The results of the long run relationship between domestic electricity consumption, GDP per capita, electricity price and degree of urbanization (Model 1) as well as the relationship between commercial and industrial electricity consumption, GDP per capita, electricity price and degree of urbanization (Model 2) are presented in Tables 4.3 and 4.4 respectively. The error correction term (ECT) is also specified to indicate the speed at which deviations from long run relationships are corrected.

Table 4. 3: Model 1: Estimated coefficients using ARDL

	ARDL Model			
	Dependent Variable: Domestic Electricity Consumption			
Variable	**Coefficient**	**Std. Error**	**t-statistic**	**p-value**
GDP per cap.	0.851***	0.092	9.240	0.000
Elect. Price	0.147***	0.039	3.750	0.001
Urbanization	1.120***	0.224	5.010	0.000
ECT	-0.678***	0.136	-4.980	0.000
Constant	-2.439**	0.951	-2.570	0.018
R^2	0.6210			
Log-likelihood	52.746			
Root MSE	0.051			
N	35			

***, **, * indicates 1%, 5%, and 10% levels of significance

Source: Author's Computation

The results from Model 1 reveal that income elasticity of domestic electricity demand is positive, significant at 1% level of significance and inelastic. In particular, a one percent increase in GDP per capita leads to a 0.85 percent increase in domestic electricity demand. Price of electricity is found to be highly inelastic, significant at 1% level of significance, and positively related to domestic electricity demand. If domestic electricity price increases by one percent, domestic electricity demand would increase by 0.15 percent. Urbanization is elastic, significant at 1% level of significance, and positively related to domestic electricity demand. A one percent increase in degree of urbanization would lead to 1.12 percent increase in domestic electricity demand. R^2 indicates that 62 percent of the variations in domestic electricity demand is explained by the explanatory variables included in the model.

Table 4. 4: Model 2: Estimated coefficients using ARDL.

	ARDL Model			
	Dependent Variable: Commercial and Industrial Electricity Consumption			
Variable	**Coefficient**	**Std. Error**	**t-statistic**	**p-value**
GDP	0.392***	0.041	9.490	0.000
Elect. Price	0.082**	0.031	2.620	0.015
Urbanization	0.140	0.104	1.350	0.190
ECT	-0.547***	0.079	-6.910	0.000
Constant	1.864***	0.528	3.530	0.002
R^2	0.894			
Log-likelihood	71.787			
Root MSE	0.037			
N	35			

***, **, * indicates 1%, 5%, and 10% levels of significance

Source: Author's Computation

The results from Model 2 reveals that GDP is inelastic, significant at 1% level of significance and positively related to commercial and industrial demand for electricity. In particular, a one percent increase in GDP leads to a 0.39 percent increase in commercial and industrial electricity demand. Price of electricity is found to be highly inelastic, significant at 1% level of significance, and positively related to domestic electricity demand. If electricity price increases by one percent, commercial and industrial electricity demand would increase by 0.08 percent. Urbanization is found to be inelastic and insignificant at 10% level of significance. R^2 indicates that 89.4 percent of the variations in commercial and industrial electricity demand is explained by the explanatory variables included in the model.

Price of electricity was found to be highly inelastic and did not yield the expected sign in both models. Price inelasticity could be due to the fact that electricity has limited substitution possibilities, and KPLC has the monopoly of supplying electricity in Kenya. One possible explanation for the positive sign of the price coefficient is price control, hence impairing the responsiveness of electricity demand to prices (El-Shazly, 2013).

The error correction term for both models has the expected sign (negative) and is significant at 1% level of significance. Coefficient for model 1 implies that deviations from the long run in the previous period are corrected in the present period at a speed of convergence of 67.8 percent, while for model 2, the speed of convergence is 54.7 percent.

4.5 Cointegration Test

The bounds test was used for testing the existence of long-run relationship between domestic electricity consumption, GDP per capita, electricity price and degree of urbanization (Model 1) as well as the existence of long-run relationship between commercial and industrial electricity consumption, GDP per capita, electricity price and degree of urbanization (Model 2). The results are as shown in Table 4.5.

Table 4. 5: Bounds cointegration test results.

		Critical F-values							
	F-statistics	0.100		0.050		0.025		0.010	
Model 1	**7.689**	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Model 2	**17.049**	2.72	3.77	3.23	4.35	3.69	4.89	4.29	5.61

The value in bold represents the computed F-statistic.

Source: Author's Computation

Since the computed f-statistic for both models is greater than the critical f-value for I(1) regressors at all levels of significance, we reject the null hypothesis of no co-integration, implying that there is co-integration.

4.6 Diagnostic Tests

The models were subjected to serial correlation test, heteroscedasticity test, and model stability test. The results for serial correlation and heteroscedasticity tests are shown in Table 4.6, while the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) plots for model 1 and model 2 are displayed in Figures 4.1 and 4.2 respectively.

Table 4. 6: Diagnostic tests.

Test	**Model 1**	**Model 2**
Serial Correlation	F = 0.084 (0.7739)	F = 1.558 (0.2240)
Heteroscedasticity	$\chi^2 = 0.086$ (0.7698)	$\chi^2 = 0.033$ (0.8556)

Figures in parenthesis indicate the p-values.

Source: Author's Computation

The null hypothesis of no serial correlation is not rejected in both models. This is because the p values for model 1 and model 2 are 0.7739 and 0.2240 respectively, which are both greater than 0.10, implying that the models are free of serial correlation. The models are also free of the problem of heteroscedasticity because the null hypothesis of homoscedasticity is not rejected, since the p values for model 1 and model 2 are 0.7698 and 0.8556 respectively which are both greater than 0.10.

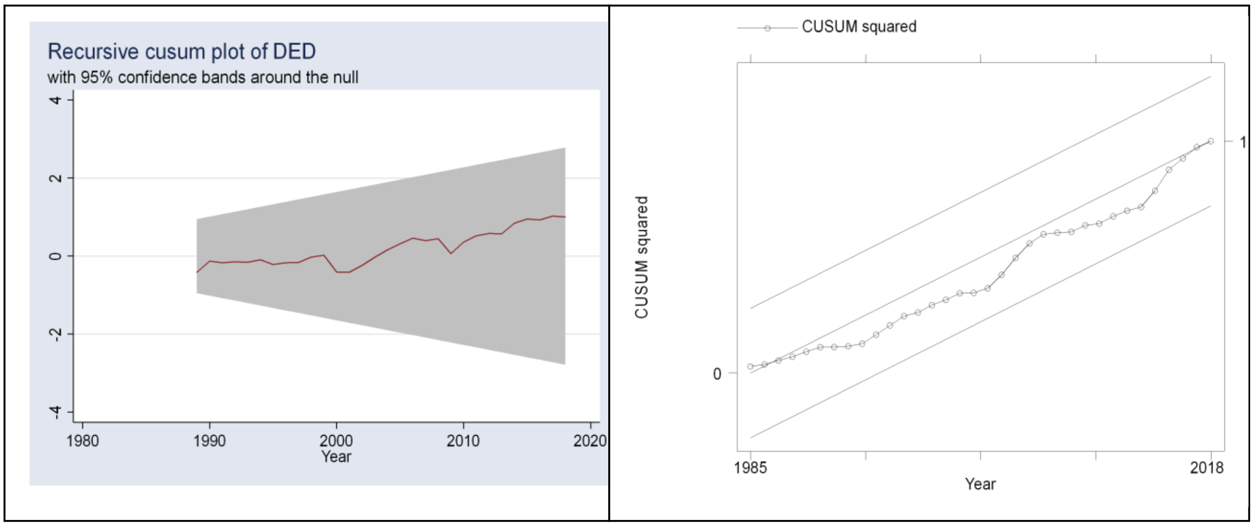

Figure 4. 1: Plot of recursive CUSUM and CUSUMQ for model 1.

Source: Author’s construction

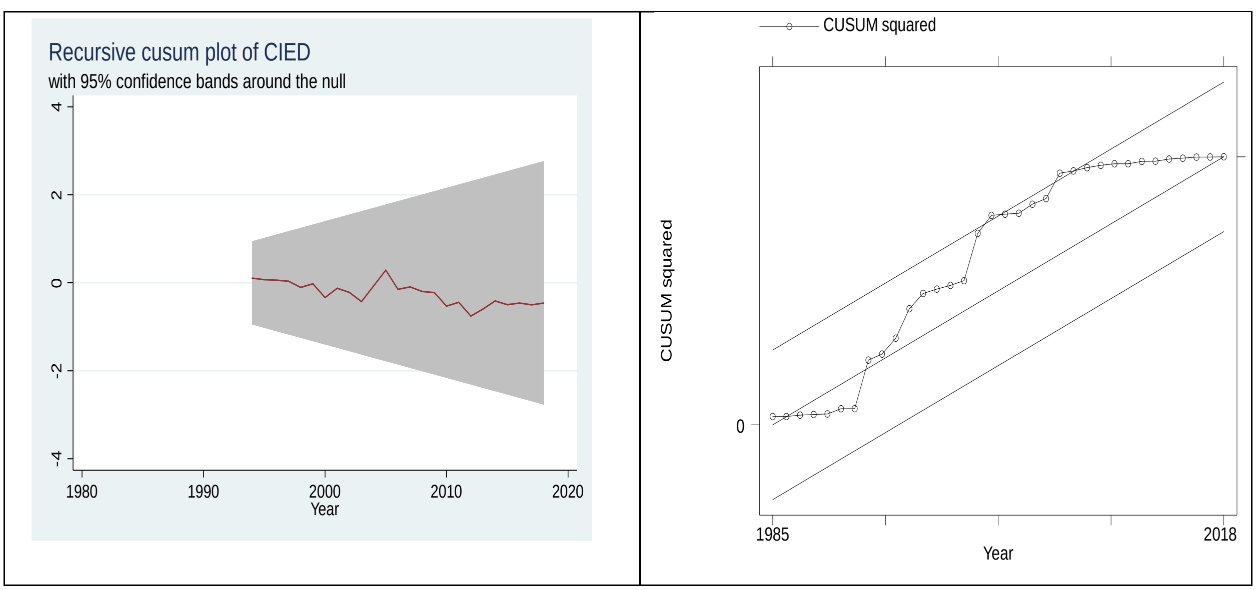

Figure 4. 2: Plot of recursive CUSUM and CUSUMQ for model 2.

Source: Author’s construction

The cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) test was carried out using a 5% percent level of significance as indicated by the critical lines. The results indicate model stability since none of the statistic crossed the critical lines for both model 1 and model 2.

4.7 Forecast of Electricity Demand

Forecasting ability of the ARDL models is evaluated by restricting the sample to the year 2010, and then using years 2011 to 2018 to examine how well the ARDL models predict domestic as well as commercial and industrial electricity demand in Kenya as shown in Figure 4.3. The mean absolute percent error (MAPE) and Theil inequality coefficient were also calculated to establish the forecasting ability of the models as indicated in Table 4.7.

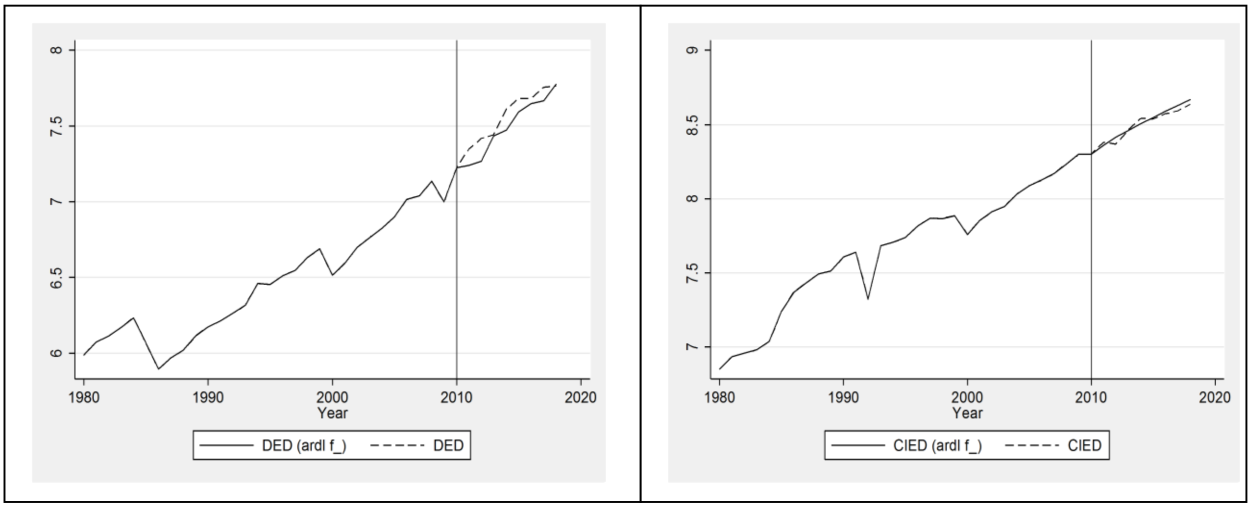

Figure 4. 3: Plots of actual and dynamic forecasts for domestic as well as commercial and industrial electricity demand.

Source: Author’s construction

The plots of the forecasted electricity demand versus the actual electricity demand shows that the values are approximately equal, thus the ARDL models accurately predicts electricity demand.

Table 4. 7: Summary statistics for forecast errors.

	Model 1	Model 2
Mean absolute percent error (MAPE)	0.00215456	0.00060427
Theil Inequality Coefficient	0.40404225	0.11300658

Source: Author's Computation

The closer the value of mean absolute percent error (MAPE) and Theil inequality coefficient is to zero, the better the forecast model. The calculated mean absolute percent error (MAPE) for model 1 and model 2 is 0.002 and 0.0006 respectively, while the Theil inequality coefficient for model 1 is 0.4 and for model 2 is 0.1. This indicates that the estimated ARDL models best track the patterns of movement in both domestic electricity demand as well as commercial and industrial electricity demand.

In order to forecast domestic electricity demand and commercial and industrial electricity demand for the period 2019 to 2030 using the ARDL model estimates, national projections of the explanatory variables were obtained as described in Table 4.8.

Table 4. 8: National projections of the explanatory variables.

Variable	Assumption	Source
GDP	GDP is predicted to grow at an annual rate of 10 percent over the forecast period.	Kenya Vision 2030 report.
GDP per capita	Predictions obtained by dividing the predicted GDP by the predicted total population over the forecast period.	Own Computation. Population predictions for the forecast period was obtained from 2019 World Population Prospects.
Urbanization	Annual degree of urbanization is predicted to be 4.23, 4.09, and 3.95 for the periods 2019-2020, 2021-2025 and 2026-2030, respectively.	2018 World Urbanization Prospects.
Electricity Prices	Average retail electricity tariffs are assumed to be as provided in Kenya's LCPDP.	Least Cost Power Development Plan (LCPDP) 2017- 2037 (ERC, 2018).

The resulting forecasts for domestic as well as well as commercial and industrial electricity demand are as shown in Table 4.9.

Table 4. 9: Electricity demand forecasts using ARDL approach.

Years	Domestic electricity demand	Commercial and Industrial electricity demand
2019	2472.61	5915.122
2020	2605.62	6186.758
2021	2710.28	5966.333
2022	2833.81	6829.014
2023	2968.63	7360.12
2024	3142.17	7068.411
2025	3315.48	7485.992
2026	3455.87	7745.619
2027	3604.52	8038.576
2028	3761.56	8756.335
2029	3927.17	8459.481
2030	4101.641	8898.563

Source: Author's Computation

The projected demand for the domestic sector in the year 2030 is estimated to be 4,101.64 GWh representing a 74 per cent rise from the year 2018, while the projected demand for the commercial and industrial sector is estimated to be 8,898.56 GWh representing a 57.6 per cent rise from the year 2018. Taking these two sectors as the key drivers of electricity demand in Kenya, total electricity consumption for the year 2030 is estimated to be 13,000.20 GWh. The obtained total electricity demand forecast was significantly lower than the forecast outlined in the LCPDP, where electricity demand is estimated to be 19,475 GWh in the year 2030 under the low case scenario (ERC, 2018).

Due to this notable difference, alternative electricity demand forecasting was done using the Long-range Energy Alternative Planning System (LEAP), which is a widely used input-output tool for energy sector policy analysis. To accomplish this, the estimation for the demand functions in

ARDL were done without taking their logarithms unlike the earlier regressions. The aim was to maintain the units of the regression variables similar to those being forecasted, thus easing the projection. The coefficients of the ARDL models for domestic as well as commercial and industrial sectors without logarithms are as shown in equations 4.1a and 4.1b respectively (See appendices 1 and 2 for results).

$$DED = -1571.293 + 0.87GDPpc + 54.28EP^{d} + 42430.69\,Urb \quad (4.1a)$$

$$CIED = -719.08 + 1.24GDPpc + 151.34\,EP^{ic} + 63278.87\,Urb \quad (4.1b)$$

Where *DED* is domestic electricity demand, *GDPpc* is gross domestic product per capita, EP^{d} is domestic electricity price, Urb is urbanization, *CIED* is commercial and industrial electricity demand, and EP^{ic} is industrial and commercial electricity price.

To carry out forecasting, the above ARDL coefficients in the models 4.1a and 4.1b were imputed in LEAP, and the independent variables were assumed to grow at a rate equal to the average annual growth rate for the last 39 years as shown in Table 4.10.

Table 4. 10: Annual growth rates for the independent variables for the period 2019 to 2030.

Variables	Annual growth rate (%)
GDP	7.5
GDP per capita	4.35
Urbanization	-0.5
Commercial and Industrial electricity price	13.2
Domestic electricity price	10.25

The values were computed as the average of the annual growth rates for the period 1980 to 2018.

Source: Author's Computation

The resulting forecasts for domestic as well as well as commercial and industrial electricity demand are as shown in Figure 4.4.

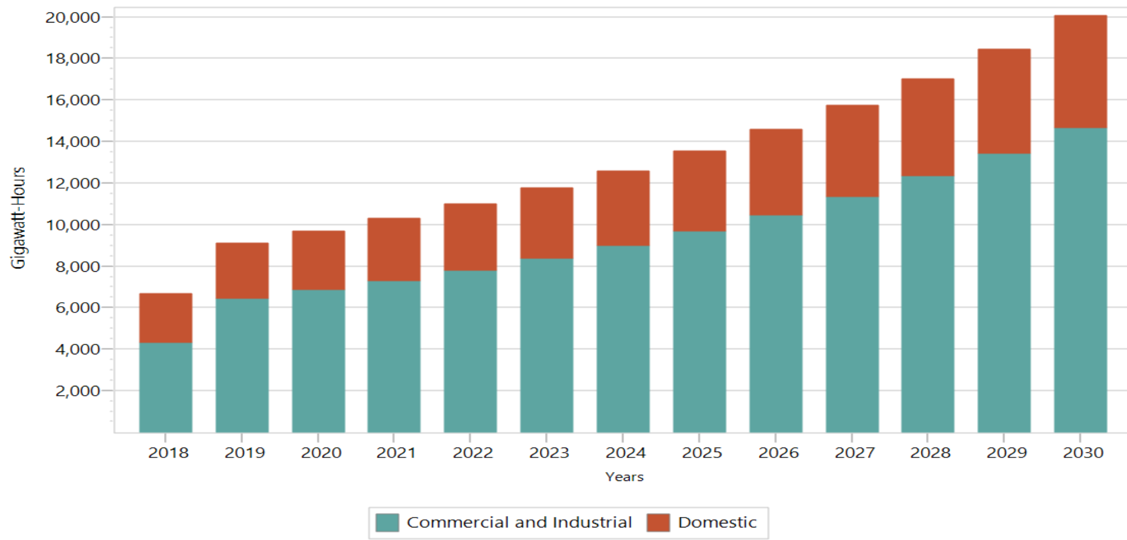

Figure 4. 4: Electricity Demand Forecast.

Source: Author's construction

The projected demand for the domestic sector in the year 2030 is 5,378.2 GWh, while the projected demand for the commercial and industrial sector is 14,667 GWh. Total electricity demand in the base year, 2018 was 11,182 GWh, and this is expected to grow to 20,045.2 GWh by the year 2030. The estimated domestic electricity demand for the year 2030 using LEAP is higher than the value obtained using ARDL by 1,276.56 GWh, while that for commercial and industrial sector is higher by 5,768.44 GWh. Electricity demand forecasts estimated using the LEAP model is comparable to the forecasts in the LCPDP, where electricity demand is estimated to be 19,475 GWh under the low case scenario and 25,195 GWh under the reference case scenario (ERC, 2018). Therefore, the results obtained using the LEAP model are considered as the basis for the analysis.

4.8 Electricity Supply analysis for various scenarios

Long-range Energy Alternative Planning System (LEAP) is a widely used input-output tool for energy sector policy analysis, particularly GHGs emissions mitigation. LEAP has three key modules: assumptions, demand and transformation. Sector wise forecasted electricity demand results are contained in the demand module. Data related to electricity generation processes such as maximum availability of plants, historical production, exogenous capacity, operating and maintenance costs, and emissions factors are inputted in the transformation module after which LEAP inbuilt calculator carries out supply side analysis, GHGs emissions analysis as well as cost analysis. Three scenarios describing how electricity generation might evolve in the future up to the year 2030 are formulated under the transformation module. Electricity generation power plants are dispatched to meet the forecasted annual demand for the period 2019 to 2030 in all the scenarios. Where necessary, processes are run up to their maximum capacity factor. Forecasted electricity generation under the three scenarios: Business as Usual Scenario (BAU), Green Energy Scenario 1 (GES1), and Green Energy Scenario 2 (GES2) are shown in Figures 4.5, 4.6 and 4.7 respectively.

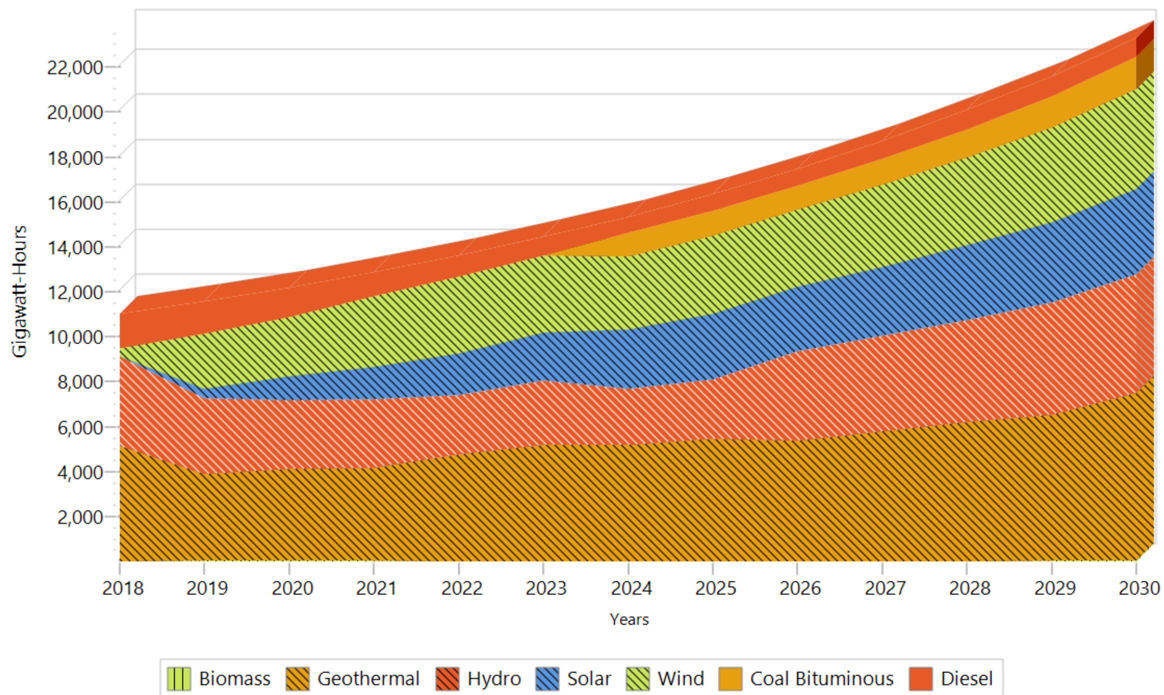

Figure 4. 5: Electricity Generation in BAU.

Source: Author’s construction

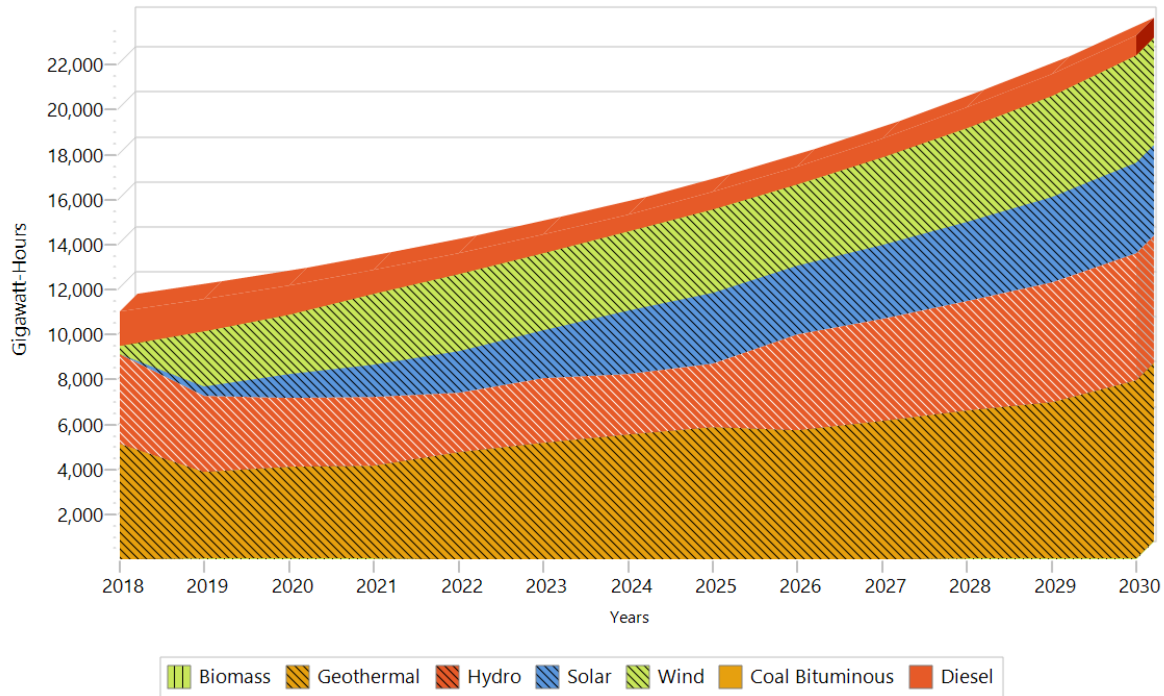

Figure 4. 6: Electricity Generation in GES1.

Source: Author's construction

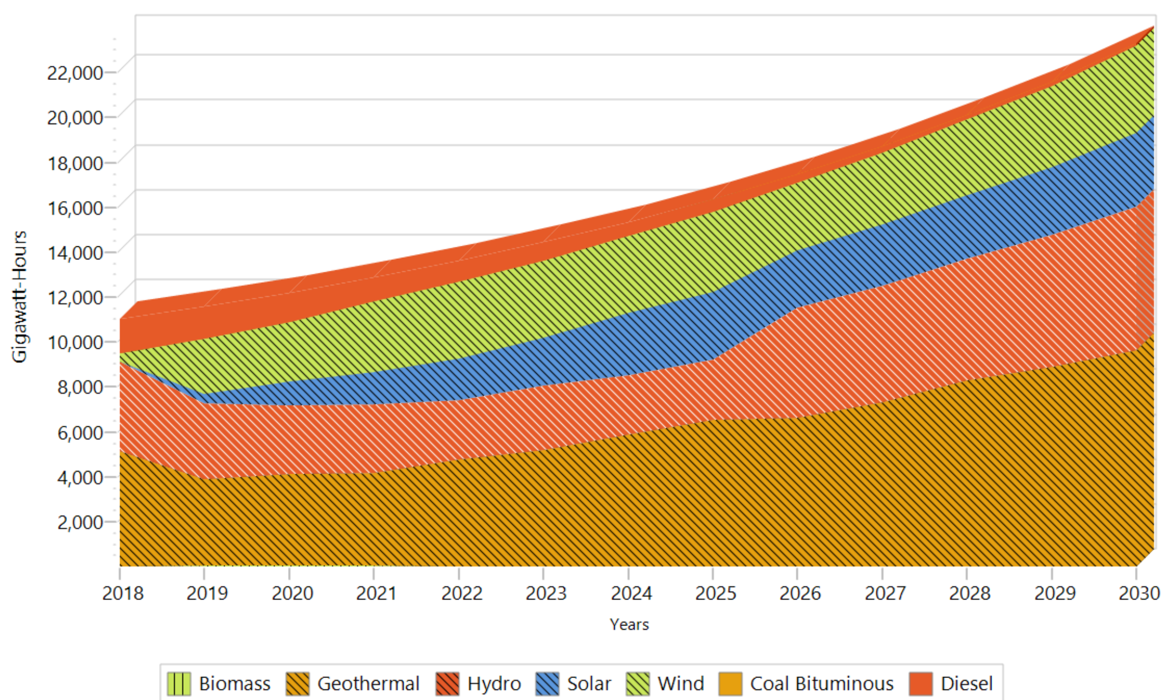

Figure 4. 7: Electricity Generation in GES2.

Source: Author's construction

Electricity generation in base year 2018 is 11,053 GWh, and electricity generation is predicted to grow to 23,308.4 GWh in the year 2030, representing 122 per cent increase. Comparison of the BAU with the GES1 indicates a reduction of generation of electricity from non-renewable resources from 8.5 percent to 3.7 percent, while similar comparison between BAU and GES2 shows a reduction from 8.5 percent to 0.4 percent.

4.9 Analysis of Greenhouse Gases Emissions from Different Scenarios

Greenhouse gases (GHGs) emissions associated with the different scenarios: BAU, GES1, and GES2 is shown in Figures 4.8, 4.9, and 4.10 respectively. Carbon dioxide, Nitrous Oxide, and Methane are the main greenhouse gases that were prioritized. These GHGs are converted to carbon dioxide equivalents (CO_2eq) using the 100-year global warming potential (GWP) estimates provided by IPCC.

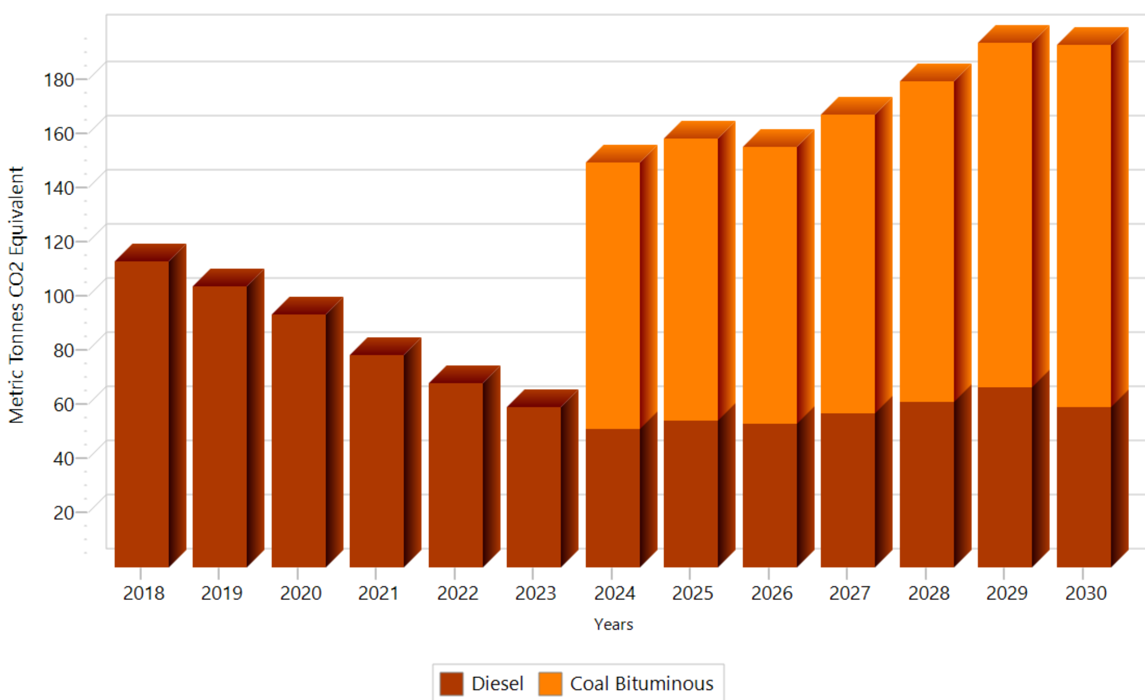

Figure 4. 8: GHGs Emissions in BAU.

Source: Author’s construction

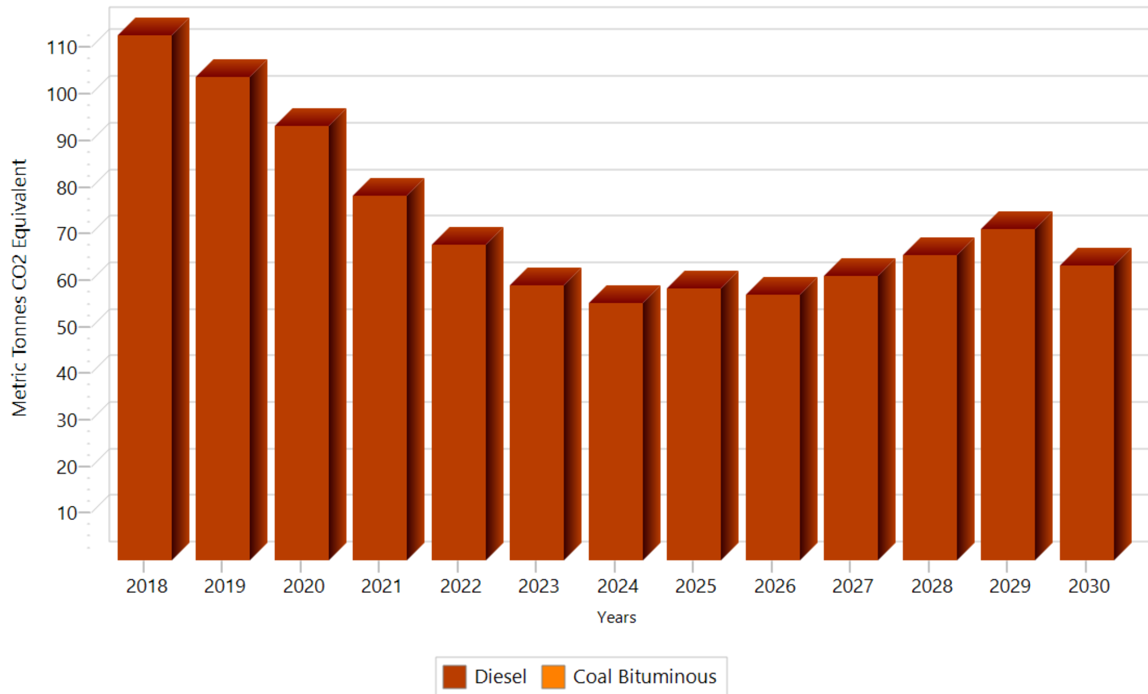

Figure 4. 9: GHGs Emissions in GES1.

Source: Author's construction

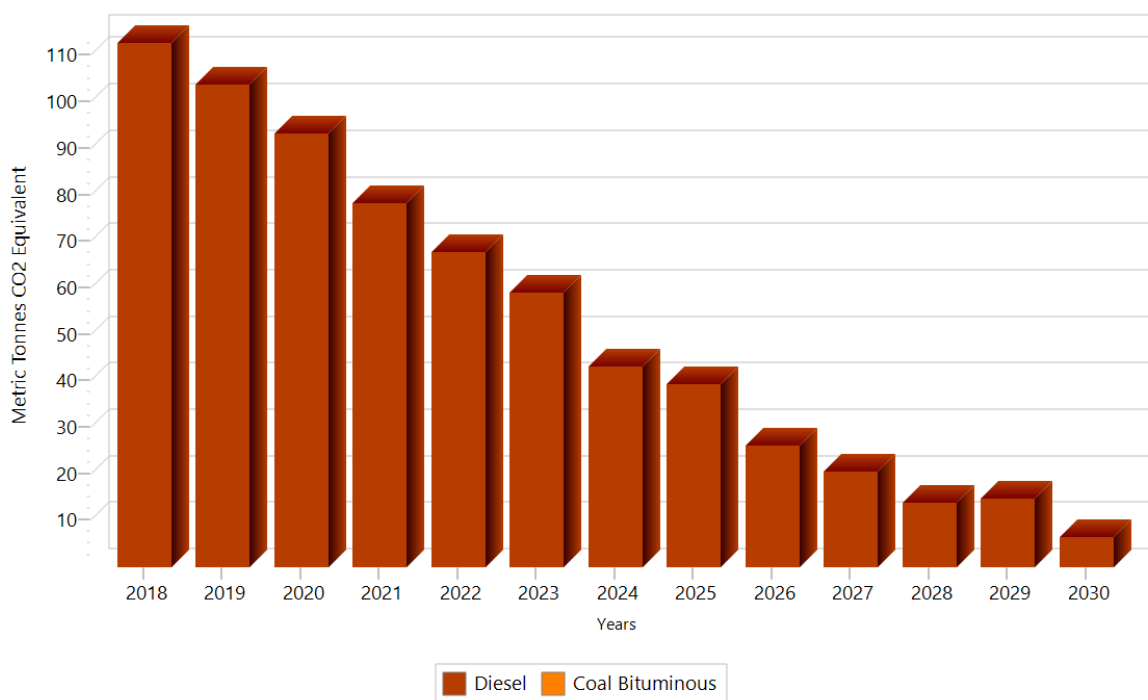

Figure 4. 10: GHGs Emissions in GES2.

Source: Author's construction

It is estimated that the GHGs emissions from electricity generation in the base year stands at 112.6 $MtCO_2eq$. However, by the year 2030, GHG emissions from electricity generation is estimated to be 192.7 $MtCO_2eq$, 63.1 $MtCO_2eq$, and 6.3 $MtCO_2eq$ for the BAU, GES1, and GES2 respectively. A comparison between BAU and GES1 shows that GHGs emissions from electricity generation will reduce by 67.3 percent, while a similar comparison between BAU and GES2 shows that emissions will reduce by 96.7 percent. Exploitation of coal for electricity generation is anticipated to begin in the year 2024, explaining the gradual increase in GHGs emissions under BAU. The main assumption under GES1 is that there is no additional exploitation of non-renewable resources for electricity generation, implying that coal power plants were not commissioned. This explains the reduction of GHGs emissions as compared to BAU. A comparison between GES1 and GES2 shows that GHGs emissions reduced by 56.8 $MtCO_2eq$, which can be attributed to progressive decommissioning of the diesel power plants as they neared their life span.

4.10 Cost Analysis

Estimated cumulative operating and maintenance (fixed and variable) costs for BAU, GES1, and GES2 for the period 2018 to 2030 are as presented in Figure 4.11. A discount rate of 12 percent was used to discount costs to the value of base year (2018).

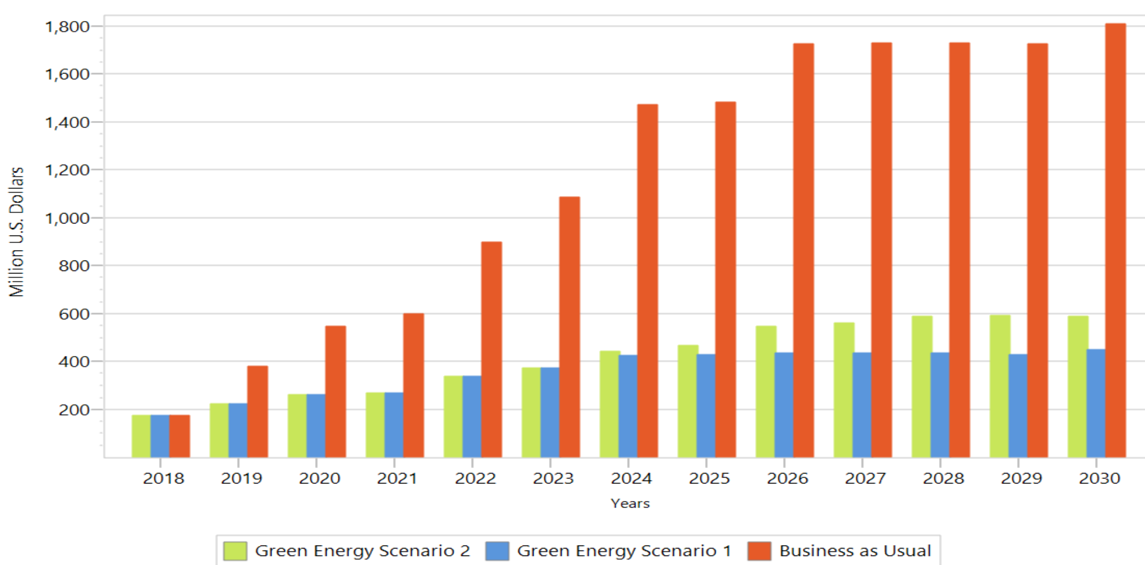

Figure 4. 11: Cumulative Fixed and Variable O&M costs for different scenarios.

Source: Author's construction

Operating and maintenance (O&M) costs are expected to rise to 1,807.8 million US dollars by the year 2030 under the BAU, while under GES1 and GES2, these costs are expected to be 448.4 million US dollars and 587.7 million US dollars respectively. A comparison of operating and maintenance costs between BAU and GES1 shows a 75.2 percent reduction, while a comparison between BAU and GES2 indicate a 67.5 percent reduction in these costs. Further, a comparison of operating and maintenance costs between GES1 and GES2 shows a 31.1 percent increase in these costs as shown in Figure 4.12. This increase is attributed to increase in fixed O&M costs as nonrenewable sources of electricity generation are substituted with renewable sources. Majority of renewable sources of electricity are available at no costs, hence the variable costs associated with them are minimal.

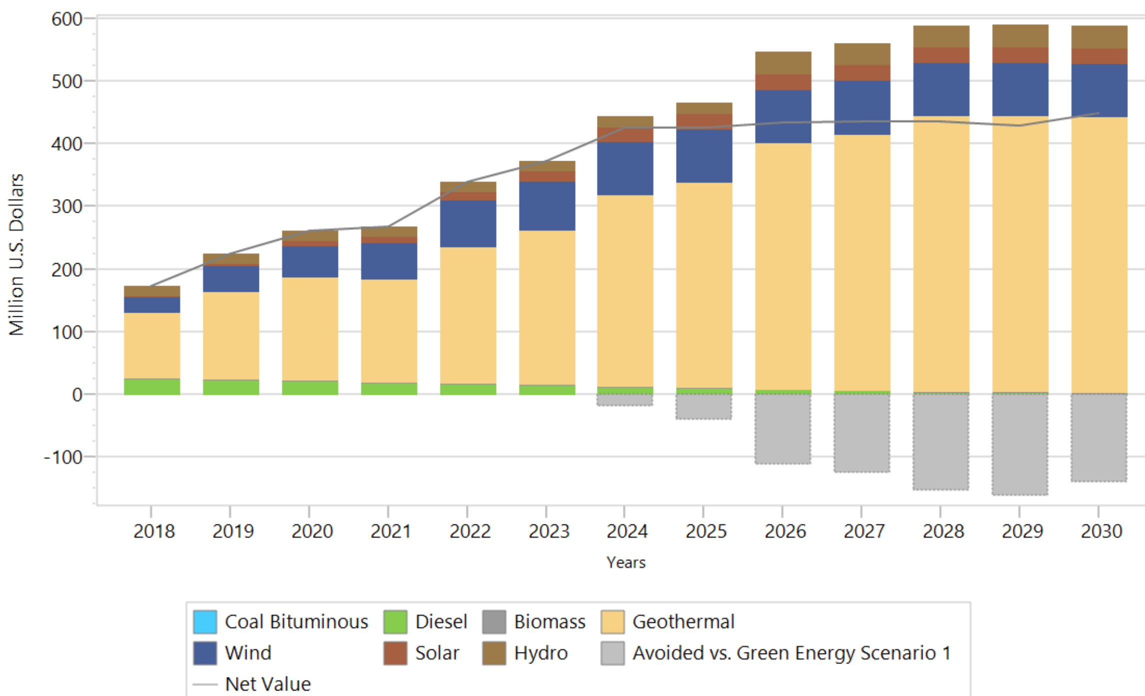

Figure 4. 12: Comparison of O&M costs between GES1 and GES2.

Source: Author's construction

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

5.1 Summary and Conclusions

The main objective of the study was to assess the effects of growth in energy demand and supply on the realization of an inclusive green economy in Kenya. Time series data for commercial and industrial electricity demand, domestic electricity demand, electricity prices, GDP, GDP per capita, and urbanization growth for the period 1980 to 2018 were collected and analyzed. Autoregressive Distributed Lag (ARDL) and Long-range Energy Alternative Planning system (LEAP) models were used to forecast domestic as well as commercial and industrial demand for the period 2019 to 2030. Electricity demand forecasts estimated using LEAP model were found to be more comparable to the forecasts in the Least Cost Power Development Plan (LCPDP), hence, the results obtained using the LEAP model were considered as the basis for the analysis. The forecasts indicated that total electricity demand will be 20,045.2 GWh by the year 2030. Given the forecasted electricity demand, the study further analyzed three possible electricity generation pathways: BAU, GES1 and GES2 using LEAP. Total electricity generated in the base year 2018 was 11,053 GWh, which was projected to increase to 23,308.4 GWh by the year 2030. Comparison of the BAU with the GES1 indicates a reduction of generation of electricity from non-renewable resources from 8.5 percent to 3.7 percent, while a similar comparison between BAU and GES2 shows a reduction from 8.5 percent to 0.4 percent.

GHGs emissions from electricity generation in the base year was estimated to be 112.6 $MtCO_2eq$. However, by the year 2030, GHG emissions from electricity generation is estimated to be 192.7 $MtCO_2eq$, 63.1 $MtCO_2eq$, and 6.3 $MtCO_2eq$ for the BAU, GES1, and GES2 respectively. Hence, GES2 has the least GHGs emissions, GES1 has moderate GHGs emissions while BAU has the highest GHGs emissions. Exploitation of coal for electricity generation is anticipated to begin in the year 2024, explaining the gradual increase in GHGs emissions under BAU. A comparison of operating and maintenance costs between BAU and GES1 shows a 75.2 percent reduction, while a similar comparison between BAU and GES2 indicate a 67.5 percent reduction in these costs. This indicates that BAU is the most expensive pathway in terms of operating and maintenance costs, GES2 has moderate operating and maintenance costs while GES1 is the most economical pathway. GES1 is associated with low operating and maintenance costs because as non-renewable sources of electricity are decommissioned, they are not substituted with the renewable resources unlike in the GES2.

5.2 Policy Recommendations

Total electricity demand is estimated to be 20,045.2 GWh by the year 2030, which represents 79.3 percent increase from electricity demanded in 2018. Kenya should exploit its untapped renewable energy potential in order to meet this demand without compromising on environment. Electricity generation is estimated to be 23,308.4 GWh by the year 2030 under the three scenarios (BAU, GES1 and GES2). This implies that regardless of the electricity generation pathway that Kenya might decide to follow, electricity demand will be met. However, it is important that the pathway chosen maximizes the welfare of individuals, not only by satisfying the demand, but also ensuring reduced emissions. This will also enable Kenya meet its NDC commitment.

GES2 has the least GHGs emissions. This implies that substituting nonrenewable sources of electricity with renewable sources can lead to significant reduction of GHGs emissions. However, this scenario is associated with the moderately high operating and maintenance costs as compared to GES1. GES1 is associated with 67.3 percent reduction in GHGs emissions when compared with the BAU scenario. This shows that if the GES1 is adapted, Kenya's NDC commitment which targets to achieve 30 per cent reduction of emissions as compared to BAU will be achieved. Another advantage of GES1 is that the associated operating and maintenance costs are minimal compared to both BAU and GES2.

Therefore, comparing the three scenarios in terms of the operating and maintenance costs and associated GHGs emissions, GES1 is the most realistic pathway that should be followed in order for Kenya to meet the growing electricity demand and achieve its NDC commitment, hence moving towards attainment of an inclusive green economy by significant reduction of carbon emissions.

5.3 Areas of Further Research

The scenarios analyzed in the study were formulated based on different electricity generation mixes. Further research on this area can include different demand side scenarios such as energy conservation. The studies can also consider disaggregating sectors into subsectors while forecasting electricity demand.

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APPENDIX 1: Estimated coefficients using ARDL for domestic sector.

	ARDL Model			
	Dependent Variable: Domestic Electricity Consumption			
Variable	**Coefficient**	**Std. Error**	**t-statistic**	**p-value**
GDP per cap.	0.873***	0.128	6.810	0.000
Elect. Price	54.277***	8.265	6.570	0.000
Urbanization	42430.690***	11029	3.850	0.001
ECT	-0.892***	0.193	-4.630	0.000
Constant	-1571.293***	532.568	-2.950	0.009
R^2	0.7252			
Log-likelihood	-185.2396			
Root MSE	67.0950			
N	35			

***, **, * indicates 1%, 5%, and 10% levels of significance

Source: Author's Computation

APPENDIX 2: Estimated coefficients using ARDL for commercial and industrial sector.

	ARDL Model			
	Dependent Variable: Commercial and Industrial Electricity Consumption			
Variable	**Coefficient**	**Std. Error**	**t-statistic**	**p-value**
GDP per cap.	1.240***	0.322	3.850	0.001
Elect. Price	151.345***	21.497	7.040	0.000
Urbanization	63278.870*	32976.720	1.920	0.070
ECT	-0. 488***	0.102	-4.790	0.000
Constant	-719.078	766.438	-0.940	0.360
R^2	0.8325			
Log-likelihood	-203.6492			
Root MSE	110.5055			
N	35			

***, **, * indicates 1%, 5%, and 10% levels of significance

Source: Author's Computation