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Energy Security and Responses to Climate Change in Selected East African countries: Focusing on Electricity Industry in Kenya

동 아프리카 국가의 에너지 안보 및 기후 변화 대응 : 케냐 전력 산업을 중심으로

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Energy Security and Responses to Climate Change in Selected East African countries: Focusing on Electricity Industry of Kenya

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Abstract

Energy security has always been a concern for countries; with modernization and increasing population, the use of energy has increased rapidly, and people's lives and national economies have become dependent on energy use. As Kenya strives to achieve its vision of universal access to electricity and Vision 2030, the national economic blueprint, the demand for electricity is evident. Therefore, the energy sector is facing extensive expansion to meet the projected electricity demand. It is imperative to invest in energy security. Initiatives must be taken in the energy sector to maintain a secure future and ensure necessary energy supply and proper distribution to support social-economic development in Kenya.

This study will examine energy security and the impacts of climate change in Kenya, including the diverse policy and institutional strategies adopted by the Kenyan government to mitigate the impact of climate change on the populace and environment. The result of this study is expected to show the optimal option for the Kenyan power system to meet the future electricity demand of the country in the medium and long term, what the future electricity supply pathway for the country could be, and lastly, how each of the electricity supply pathways affects costs and the environment. The situation in Kenya is compared with the situation in selected East African countries. This study aims to identify the demand-supply gap in the electricity sector, devise integrated energy planning and implementation policies derived from the analysis, and finally, to analyze the short- and long-run relationship between energy security and environmental sustainability.

This study has applied the energy security index (ESI) model to analyze the availability, affordability, accessibility, acceptability, and efficiency dimensions of energy security. The energy security index model is constructed in three steps: calculation of value indicators, where the value of each matrix is calculated using related formulas to allow synthesis of the results from the multiple indicators. Normalization of indicators is done to all the scores or sets of scores to make data comparison more straightforward by scaling the scores between 0 and 1, where 0 characterizes the worst performance and 1 characterizes the best performance. The last step is evaluation. Some indicators show better results when lower, such as emission intensity, energy intensity and power distribution and losses. For supply security, diversification self-sufficiency, access to electricity and electricity consumption per capita, the higher the score, the better.

Based on the study, the following policy recommendations are put forth for policymakers, decision makers and stakeholders in the Kenya electricity industry to consider: The government should increase its share of alternative and renewable energy resources to cope with the expected effects of climate change, which affect hydroelectric power generation, currently the dominant source of power, and increase the security of supply. The government should also diversify its energy mix to reduce dependency on a few technologies. Diversification will insulate the country from energy disruption and strengthen energy security. Lastly, the government should promote technology and efficiency innovations that are key for mitigating the expected effects of future climate change and improving energy security, and thus would likely serve as an engine of economic growth.

Keywords: energy security, climate change, power sector, East African Countries.

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Chapter 1
Introduction

1.1. Motivation

Energy security has always been a concern for Kenya. With modernization and an increase in population, the use of energy has increased rapidly, and people's lives and the national economy are becoming dependent on the use of energy (Ayoo, 2020). Initiatives need to be taken in the energy sector to ensure a secure future with the necessary energy supply and proper distribution to support social-economic development in Kenya (Vera & Langlois, 2007). Energy security can be described in many ways. In this paper, I will simply call it "the assurance of the uninterrupted supply of energy at an affordable price, while respecting environmental concerns" (Hughes, 2012).

The Kenyan economy is still under development and, therefore, requires a relatively large amount of reliable, sustainable, clean, and secure energy services at the least cost while protecting the environment to bring about the transformation of social and economic development (LCPDP 2019–2039). It is, therefore, prudent that all sectors have access to electricity supply, especially in the manufacturing and service areas. Adequate supply will make the country more competitive in the domestic and international markets.

According to Kenya Least Cost Power Development Plan (LCPDP 2019–2039) demand-supply balance reference forecast, the demand-supply gap is still wide and is expected to close. For this to happen, we need more energy in the grid. There is also a mismatch between generation and consumption that needs to be addressed (LCPDP, 2019).

According to the Sessional Paper No. 4 on Energy of 2004, the impact of electricity on the total national energy intake stood at 22% compared to 68% from wood, 9% from petroleum, and 1% from renewable sources. Electricity is imperative for economic development, and access to electricity is correlated with a high quality of life. Energy security, especially in the electricity industry, depends on the availability of energy resources and the capacity of the electrical infrastructure. However, Kenya is not fully rich in energy resources; energy insecurity levels can be improved by diversifying the number of suppliers as well as increasing the amount of the nation's energy mix that is based on renewable energy resources. Security also depends on upgrading electrical infrastructures (transmission and distribution systems) and operating under quality standards.

The electricity sector has a significant impact on a nation's economic, social, and environmental scope. For these reasons, it must be protected from failure and from the risks that affect the energy supply. The electricity industry is important in terms of energy security because it is sensitive to disruptions in the supply of the required commodities and unexpected price fluctuations and their negative effects on social, economic, and environmental factors. The main concern of electric energy security is to guarantee the availability and accessibility of sufficient amounts of power and energy to meet demand requirements (Balat, 2010).

This study examines energy security and the responses to climate change in Kenya, including the various policy and institutional strategies adopted by the Kenyan government to mitigate Kenya's impact on the populace and environments. The study seeks to progress a qualitative method of evaluating energy security that is suitable and practical for the case of Kenya. This method will constitute a set of indicators that address the main aspect of energy security. The study will introduce the conceptual background of energy security concepts, which permits selecting and combining distinctive concepts into accessible measures. The method used will quantify the energy security of Kenya.

1.2. Research Questions

Based on the research motivation, this study seeks to answer the following questions:

i. How to meet future electricity demand in the medium and long-term?
ii. What can be the future electricity supply pathway for the country?
iii. How would each of the electricity supply pathway impact cost and environment?

1.3. Research objectives

In answering the above- mentioned research questions, bellow objectives were adopted:

i. To identify the demand-supply gap in the electricity sector
ii. To come up with integrated energy planning and implementing Policies derived from the analysis
iii. To analyze the short and long run relationship between energy security and environmental sustainability

1.4. Methodology

This study will be carried out through the energy security index model by analyzing energy availability, affordability, accessibility, acceptability and efficiency measures in the Kenya power system for the period between 1990– 2017. The study examines the best ways to meet future electricity demand in the medium and long term and proposes an optimal electricity pathway. Finally, the study analyzes how each of the electricity supply pathways affects costs and the environment to recommend policies in the electricity sector.

This study, therefore, uses the Energy Supply Security Index Model (ESSIM) to evaluate several relative indicators corresponding to a given system. The study also looks at what the various indicators reveal about energy security, the highest and lowest values of the indicators over the study period, and concepts from economic theory that are generally applicable to the operations of the different systems that make up the electricity industry supply chain in Kenya.

1.5. Scope of the study

The study evaluates energy security and response to climate change in selected East African countries, focusing on the electricity industry in Kenya over 1990–2017, by assessing the actual energy consumption and actual energy supply during this period. The result of the Kenyan analysis is then compared and contrasted in terms of availability, affordability, accessibility, acceptability, and efficiency, with results from selected East African countries. The comparison is conducted to identify the optimal electricity supply pathway that meets future electricity demand in the medium and the long term while respecting the environment.

1.6. Significance of the study

This study aims at quantitatively examining energy security in the electricity industry, defined as having available energy resources for all citizens in sufficient supply while protecting the environment, in both the long and short term (Jegen, 2009). The study will inform the formulation of policies intended to support attaining government targets to achieving universal access to electricity as a key pillar of powering the country's development agenda.

Energy security is critical to Kenya's realization of its Vision 2030, which seeks to transform Kenya into an industrialized middle-income nation providing a high quality of life to all Kenyan citizenry. The Government's "Big 4 Agenda," which addresses food and nutrition, security, manufacturing, affordable housing and health care, unveiled by the president in 2017, is supported by the availability of adequate and competitively priced energy. The result will also be useful in advising about the development of future energy supply pathways and how they affect the cost and environment (Kenya National Electrification Strategy (KNES), 2018).

1.7. Thesis structure

This study consists of six chapters. The first chapter introduces the study and clarifies the motivation of the research, the research question, research objectives and the research outline. Chapter 2 gives an overview of the energy sector, including energy security in Kenya.

Chapter 3 is the literature review, Chapter 4 is the methodology, Chapter 5 is the result and discussion, and Chapter 6 is the conclusion and policy recommendation.

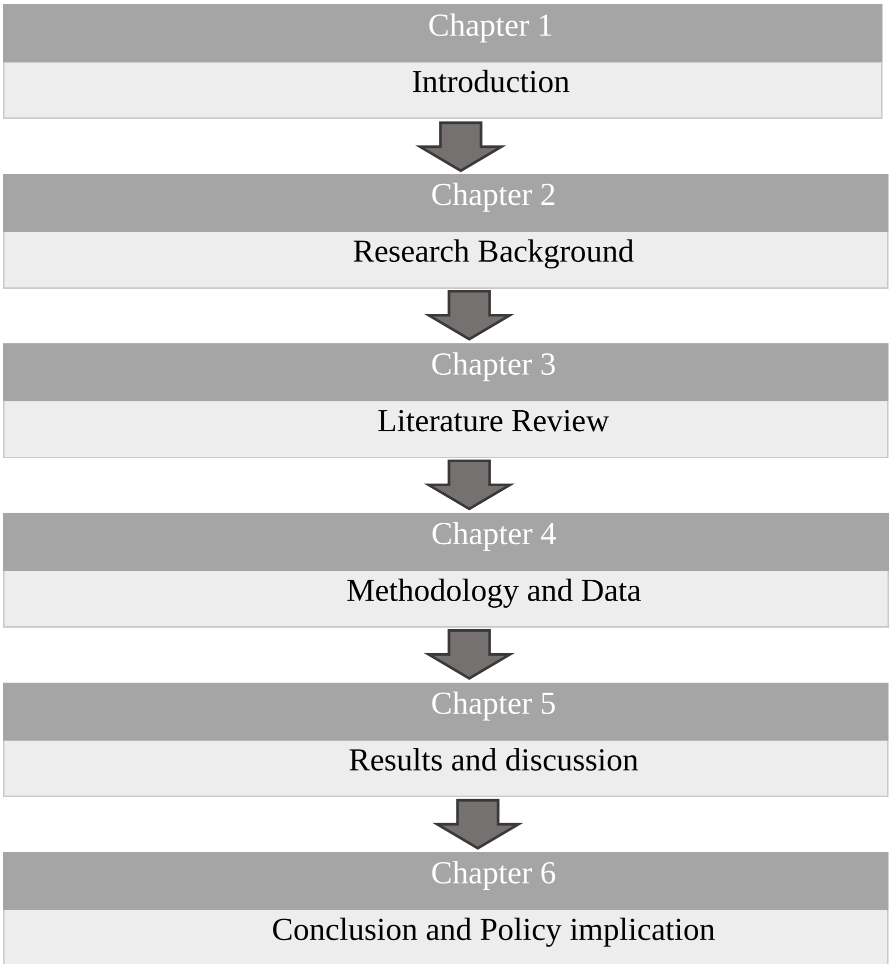

Figure 1.1. The structure of the study

Chapter 2

Research Background

2.1. A Brief History on the Kenya Power Sector

The history of the power sector in Kenya can be traced to 1922, when two companies merged to form East African Power and Lighting Company (EAP&L). The companies were Nairobi Power and Lighting Syndicate and Mombasa Electric Power and Lighting Company, which were both formed in 1908. Kenya Power Company (KPC) was later established in 1954 as a subsidiary to set up transmission lines between Kenya and Uganda to ease the importation of power to Kenya. EAP&L was later renamed Kenya Power and Lighting Company Limited (KPLC) in 1983, as most of the Kenya operations were largely based in Kenya (LCPDP-2018). The company later re-branded and was renamed Kenya Power, which is its current name.

The power sector in Kenya has been experiencing reorganization and reform since the 1990s, resulting in the development of an energy policy in 2004 and the Energy Act 2006. In the mid-1990s, the Kenyan government formally opted to liberalized power generation as part of the sector reforms in 1996. Among the reforms implemented was the segregation of state utilities in 1997. The Kenya Electricity Development Company (KenGen) remained state-owned in its entirety and was in charge of the generation assets, while KPLC took up the control of all distribution and transmission. The Electricity Regulatory Board, currently known as Energy and Petroleum Regulatory Authority (EPRA), was also established under the 1997 Electric Power Act as the sub-sector regulator.

In the same way, the energy regulatory commission and the rural electrification authority, currently known as the Rural Electrification and Renewable Energy Corporation (REREC), was established through policy reforms. The Sessional Paper No. 4 on Energy of 2004 also allows for establishing the geothermal development company (GDC), a special purposes vehicle for geothermal resource development. The Kenya Electricity Transmission Company (KETRACO) was established as a state-owned transmission company. The Nuclear Power and Energy Agency, formerly Kenya Nuclear Electricity Board (KNEB), is also a state-owned corporation established under the Energy Act 2019. It is charged with promoting and implementing the Kenya Nuclear Power Program and carrying out research and development for the energy sector (LCPDP 2019–2039).

2.2. Energy Policies and Institutions in Kenya

Kenya has enacted several policies by way of institutions, policies, and legal frameworks, which are updated from time to time, to govern the energy sector. The country set out vital liberalization in the sector by way of reforms after the mid-1990s as a result of the enactment of the Electric Power Act of 1997, which was later followed by the Energy Act of 2006. The legislation separated the functions of generation from transmission and distribution in the electricity sub-sectors; this extends to procurement, distribution, and pricing of petroleum, which was previously regulated through the Petroleum Act of 1994 and the Petroleum Development Fund Act of 1991. The Energy Act brought together all the laws related to the energy sector and laid out the establishment of the Energy Regulatory Commission (ERC), currently known as EPRA, as the sector regulator.

2.2.1. *Policies and Strategies*

i. Kenya Vision 2030. This plan is the national economic blueprint for long-term development. It is motivated by a collaborative objective for a better society by the year 2030. The aim of Kenya Vision 2030 is to make the country internationally competitive and prosperous with a high standard of living. It aims to transform the nation into a newly industrializing, middle-income country with a high quality of life for all Kenyan citizens in a clean and secure environment. The Vision 2030 recognizes energy as an enabler to achieving development and, therefore, maps the growth of energy generation, and, subsequently, increased efficiency in energy consumption. This growth is to be realized through a sustained institutional reform in the energy sector, including a strong regulatory framework, encouraging private sector participation in power generation, and securing new sources of energy through extending the exploitation of local geothermal resources, coal renewable energy sources, and regional interconnections. These targets will be achieved through continued institutional reforms in the energy sector, including a strong regulatory framework, encouraging independent power producers to participate in power generation, and detaching generation from distribution, as well as exploring new sources of energy through the exploitation of geothermal power, coal, and renewable energy sources. The plan also seeks interconnection between Kenya and other energy-surplus countries neighboring Kenya (Government of the Republic of Kenya, Vision 2030, 2013)

ii. **Sessional Paper.** The Sessional Paper No. 4 of 2004 is a policy document that binds the liberalization reforms enacted in the energy sector in the mid-1990s. Kenya's vision is to foster equitable access to quality energy services at the least cost while preserving the environment. The paper lays out the policy framework whereupon cost-effective, affordable, and adequate quality energy services are made available to the domestic economy on a sustainable basis over 2004–2023.

iii. **Rural Electrification Master plan.** This is the master plan for rolling out rural electrification through the Rural Electrification Program, also known as the last mile rural electrification strategy. This program is managed by the REA (now REREC) and is updated on an annual basis to capture the milestones attained and the needs of the rural population in regard to electricity connectivity. The main financier of this project is the government of Kenya, and it is supported by various development partners (MoEP, 2016).

iv. **Feed-in Tariff (FIT) Policy.** In 2008, a feed-in tariff (FIT) policy was introduced, reviewed and published in 2010 to give investment security to renewable electricity generators, reduce administrative and transaction costs, and encourage private investors to establish independent power production (IPPs). With the modification of the 2008 FIT, the current tariffs now cover solar-, geothermal-, and biogas-generated electricity. These tariffs also apply to grid-connected plants with the approval of the PPAs granted by the ERC (Boampong & Phillips, 2016; Ndiritu & Engola, 2020).

v. **National power planning**. The Energy Act of 2006 assigned responsibility for developing indicative national energy plans to the Energy Regulatory Commission (ERC), which regulates electrical energy, petroleum and related products, renewable energy, and other forms of energy. ERC established a multi-stakeholder committee within the electricity sub-sector responsible for preparing the Least Cost Power Development Plan (LCPDP) on a biennial basis. The purpose of the LCPDP is to guide stakeholders with respect to how the electricity sub-sector plans to meet the country's energy needs for subsistence and development at the least cost to the economy and the environment.

vi. **Last Mile Connectivity Project**. This project was launched in 2015 to scale up connectivity in rural and peri-urban areas by providing grid extension subsidies to enable consumers to get electricity supply at an affordable cost. The project is financed by the African Development Bank (AfDB), the World Bank, the French Development Agency (AFD) and the European Investment Bank (EIB).

vii. **Kenya Off-grid Solar Access Project**. This project addresses the provision of electricity to parts of the country not served by the national grid using solar mini-grids. It was started in 2017 and is expected to end in 2023 with financing from the World Bank (Kasonzo, 2020).

viii. **Time-of-use Tariff.** This fee structure commenced in 2017, targeting industrial and commercial consumers with the objective of spurring growth in the manufacturing sector through increased production hours and shifting of demand from peak to off-peak periods.

ix. **Energy Efficiency and Conservation (EEC)**. The EEC is a policy and legal framework provided in Sessional Paper No. 4 of 2004 and the Energy Act of 2006. The Centre for Energy Efficiency and

Conservation was established by the Ministry of Energy and Kenya Association of Manufacturers to carry out energy audits, build capacity in EEC, create public awareness, and administer annual energy management awards. A savings of approximately 45 MW was realized through audits.

x. **Energy Act No. 12 of 2006.** This act came into effect proceeding the proposals of the Sessional Paper. The Energy Act No. 12 of 2006 was established to replace the Electric Power Act No.11 of 1997 and the Petroleum Act, Cap 116 of 1994. The act merged regulation and enhancement of all energy resources in the country. This, in turn, led to the establishment of the Electricity Regulatory Commission (ERC) that set out the prices and regulations for the energy sector for the producers and distributors of electrical power. Among others, Kenya Electricity Transmission Company (KETRACO) was given a mandate to build new transmission lines and substations with government financing or concessionary funding from development partners. The Geothermal Development Company (GDC) was formed to explore and produce power from geothermal steam and sell it to KenGen or other independent power producers (IPPs). In addition, the act created the Energy Tribunal, with the mandate to hear appeals of the decisions of the Energy Regulatory Commission (ERC). ERC and the Tribunal are separate regulatory bodies independent of state influence. At the end of the reorganization, KPLC was left with transmission lines developed before the formation of KETRACO.

2.2.2. *Energy Sector Institutional Framework in Kenya*

The energy sector reforms outlined in the Sessional Paper No. 4 of 2004 called for the separation of functions in the electricity sub-sector. These reforms laid the foundations for the separation of generation from transmission and distribution and the liberalization of procurement, distribution, and pricing of petroleum products in the country.

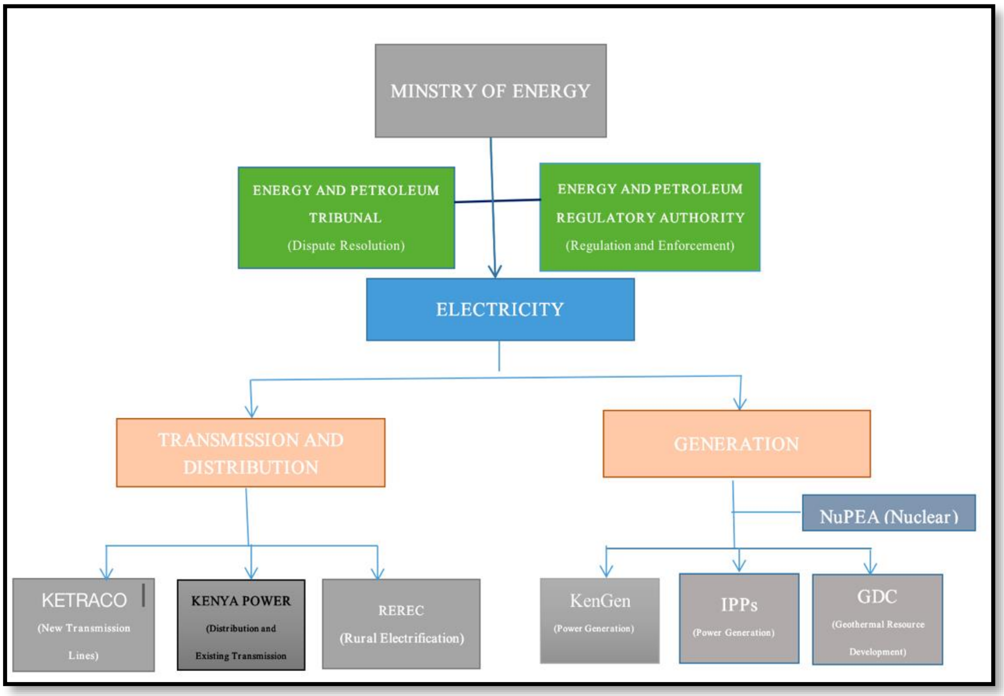

Figure 2.1. Institutional framework in the Power Sector

Source: modified from lcpdp (2019-2039)

2.2.2.1. Energy Policy Making Institutions

- **Ministry of Energy.** In Kenya, the Ministry of Energy has been mandated to coordinate the development of energy-related strategies and policies. This is done in collaboration with other state agencies such as the ERC and the Energy Tribunal.

i. **Energy Tribunal**. The Energy Act, 2006, established the Energy Tribunal as the authority that hears petitions on decisions that the energy regulator, ERC, has made.

ii. **Energy Regulatory Commission**. The Electricity Regulatory Board (ERB) was established in 1998 by the Electric Power Act. It is an independent government agency with the sole authority to regulate the energy sector. Responsibilities of ERC include, amongst others: continuously review end-user tariffs, approve power purchase agreements for new energy projects, ensure competitiveness in the sector, mediate consumer conflicts, and ensure environmental sustainability in the execution of energy projects.

2.2.2.2. Electricity Generation Institutions

i. **KenGen** is the state energy-generating company that is majority-owned by the government and minority-owned by the public. KenGen contributes about 82.1% of the total installed capacity of electricity generation, while the private sector generates about 15.2%, and imports account for about 2.4%. The state-run Rural Electrification Program contributes the rest. KPLC is the state-run electric utility company that is owned jointly by the government and investors. It is responsible and has the monopoly for power transmission and distribution and is authorized to enter into energy purchase contracts with IPPs. These two companies are the key players in the power sub-sector. They are also mandated to raise funding for system expansion with and without state guarantees.

ii. **Geothermal Development Corporation (GDC).** Kenya has a huge potential in geothermal energy resources. Through the Energy Act, 2006, the government established the Geothermal Development Corporation (GDC) as a government institution to exploit geothermal resources. This mandate is executed through surface exploration and drilling for steam pockets. The steam supply is used for power generation. GDC also performs maintenance of the infrastructure and geothermal reservoirs for uninterrupted steam supply and researches innovation in alternative uses of geothermal energy for economic development.

iii. **Independent Power Producers (IPPs).** These are private-sector entities engaging in power generation, which was not possible until 1997. So far, IPPs are actively generating about 187 MW combined installed capacity in the country. This contribution is expected to grow in both power generation and distribution.

2.2.2.3. Transmission and Distribution Institutions

i. **Kenya Power and Lighting Company (KPLC)** has had a monopoly in the distribution of commercial and domestic electricity. Regardless of policies and strategies on electricity tariff improvement and organizational restructuring, the company has not demonstrated improved performance in the financial market. This performance has hindered entrance to both domestic and international money markets, which would lead to infrastructural reinforcement and expansion. Poor financial performance has also greatly affected the degree of onerous payment security guarantees from financiers and private power sector players, which have worsened the company's financial situation. Further reforms are needed to improve performance and create a power market structure that is attractive internationally and locally.

ii. **Kenya Electricity Transmission Company (KETRACO)** is a state organization established to develop new, high-voltage electricity transmission infrastructure. This is key in the national transmission grid, in line with the long-term development plan, Kenya Vision 2030. KETRACO plans, designs, builds, and maintains electricity transmission infrastructure, including associated substations.

iii. **Rural Electrification and Renewable Energy Corporation (REREC).** Following the enactment of the Energy Act 2019, the Rural Electrification Authority (REA) was renamed the Rural Electrification and Renewable Energy Corporation (REREC). REREC has an expanded mandate of spearheading Kenya's green energy drive, in addition to fast-tracking rural electrification in Kenya. Both mandates support the achievement of sustainable socio-economic development.

iv. **Independent Power Producers (IPPs)** are private investors in the power sector involved in generation, either on a large scale or developing renewable energy under the feed-in tariff policy. As of December 2019, IPPs accounted for 1,013 MW of installed capacity.

v. **Nuclear Power and Energy Agency (NuPEA).** It is the nuclear energy program implementing organization and is responsible for promoting the development of nuclear electricity generation in Kenya and carry out research, development and dissemination activities, and capacity building in the energy and nuclear power sector.

2.3. Reforms in the Power Sector

The new Constitution 2010 brought about the review of the energy sector policy, leading to the enactment of the Energy Act No. 1 of 2019, which came into force in March 2019. Through the review, the Ministry of Energy has developed a roadmap for the execution of the Act. The reforms are:

i. Formation of an inter-ministerial Renewable Energy Resources Advisory Committee (RERAC).
ii. Expansion of the mandate of the Nuclear Power and Energy Agency formally (NuPEA) and the Kenya Nuclear Electricity Board (KNEB) to include capacity building in the energy sector.
iii. Development and implementation of an Integrated National Energy Plan, which incorporates county energy plans.
iv. Providing for open access to the transmission and distribution networks, with EPRA mandated to designate a system operator and encourage regional interconnections to enhance regional electricity trade.
v. Establishment of the Energy Efficiency and Conservation Agency (EECA) as the national public entity promoting energy efficiency and conservation.
vi. Provision for county governments to allocate land for the development of energy infrastructure for national energy projects.
vii. Provision for the national government to facilitate the development of a Resettlement Action Plan Framework for energy-related projects.
viii. Provision for delineation of roles between the national government and county governments in consultation with all stakeholders to avoid overlap of functions.

ix. Provision for viable financing options from local and international sources for cost-effective utilization of national energy resources, ensuring a competitive investment climate.

2.4. Regional Integration

The Kenya-Ethiopia 500 kV HVDC bipolar line is expected to be completed in 2020, while the Isinya-Singida 220 kV and the Lessos-Tororo 220 kV interconnectors are at an advanced phase of construction. This integration is intended to facilitate regional trading and ensure that power can be exchanged in the region. The new lines will boost grid stability and allow for the introduction of more renewable technologies, even when production from those renewable sources is intermittent.

2.5. Energy Sources in Kenya

The power generation mix comprises 43.79% geothermal, 32.55% hydro, 11.29% fossil fuels, 10.37% wind and 0.52% solar. Figure 3 shows the evolution of the generation mix from 2016/17 to 2018/19.

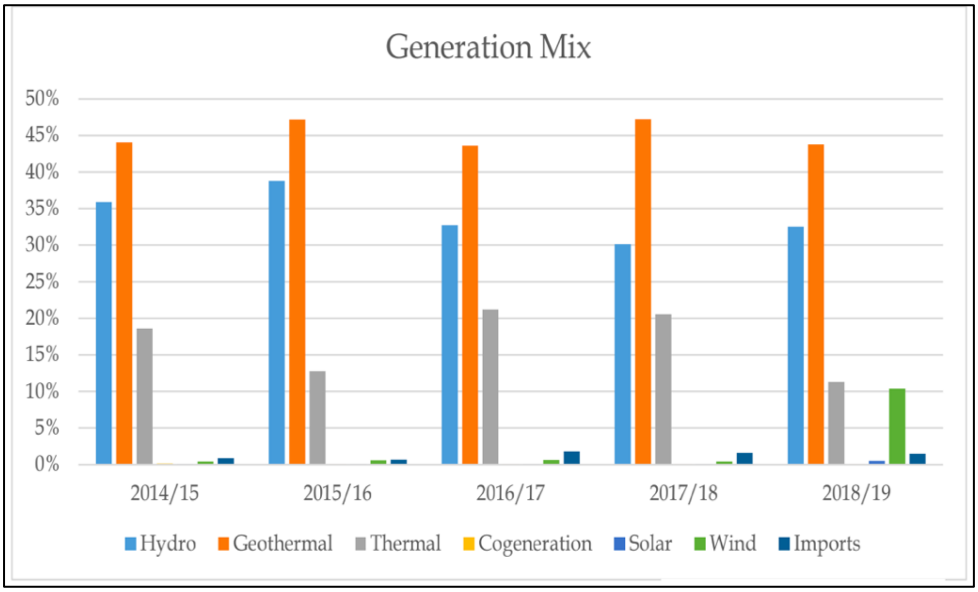

Figure 2.2. Generation mix

Source: Kenya Power and lighting Company

2.6. Electricity Demand, Supply, Consumption, Transmission and Distribution Patterns

2.6.1. *Electricity Demand*

The demand for electricity has seen an upward trend in the country over the past decade. The peak demand increased from 1,512 MW in FY 2014/15 to 1,882 MW in FY 2018/19, as shown in Figure 6. This illustrates an average annual increase of 4.89% (LCPDP 2019–2039 revised July draft final).

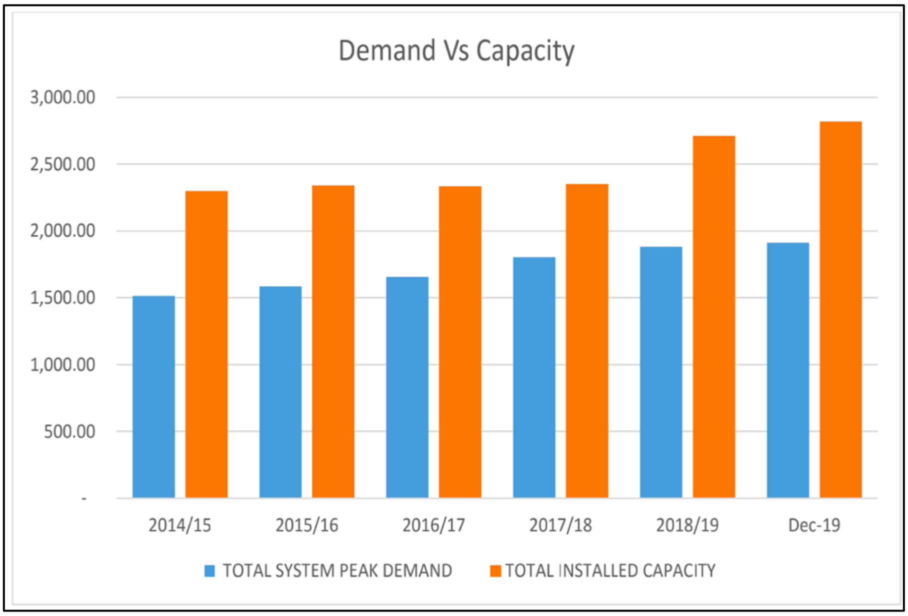

Figure 2.3. Electricity Demand Vs Capacity

Source: Kenya Power and lighting Company

The increase in peak demand is linked with the increasing number of consumers connected to power during that period. The nation has seen a significant rise in the number of customers connected, from 3,611,904 reported in the fiscal year 2014/15 to 7,067,861 reported in the fiscal year 2018/19. Rural connections are approximately 20% of the total, at 1,409,256 customers. This represents an annual average increase of 19.14% that can be ascribed to the accelerated electrification programs.

2.6.2. *Electricity Supply*

There has been a considerable rise in installed generation capacity over the past years, from 2,299 MW in FY 2014/15 to 2,712 MW in FY 2018/19, exhibiting an annual average growth rate of 4.52%. The installed capacity increased over time, and by December 2019, the installed capacity was 2,819 MW. The peak demand also increased from 1,512 MW in FY 2014/15 to 1,882 MW in FY 2018/19, an annual average rise of 4.89%. A peak demand of 1,912 MW was reported in October 2019. KenGen accounts for 62.97% of the sector's effective generation capacity, as it is the largest power generator in the country. The IPPs produced 35.95% of the power generated during the period. Isolated grid generation covered by the Rural Electrification Program (REP), executed by REREC, aggregated to less than 1.07%.

Table 2.1. Installed and Effective Capacity (2019)

	Installed MW	**% Installed Capacity (MW)**	**Effective*/ Contracted MW**	**% (effective)**
Hydro	826	29	805	29
Geothermal	828	29	816	30
Thermal (MSD)	689	24	660	24
Thermal (GT)	60	2	56	2
Wind	336	12	326	12
Biomass	28	1	24	1
Solar	51	2	50	2
Imports	0	0	0	0
Total Capacity MW	**2819**	**100**	**2736**	**100**

Source: Kenya Power and lighting Company

The installed capacity mix encompasses 29.31% of hydro, 24.45% thermal (MSD), 2.13% thermal (GT), 29.39% geothermal, 11.92% from wind and 1.81% from solar. Kenya's present effective installed (grid connected) electricity capacity is 2,736 MW as shown in Table 2.1.

2.6.3. *Consumption*

Electricity consumption has shown an upward progression in the last 5 years. Consumption rose from 7,655 GWh in the 2014/15 fiscal year to 8,769 GWh in the 2018/19 fiscal year; this is an annual increase of 3.9%. The highest increase of 5.7% was recorded in 2014/15. The growth can be attributed to expansion among all consumer groups facilitated by Kenya National Electrification Strategy's (KNES) plan to provide universal access to electricity by 2022. Table 2.2 shows a summary of trends in consumption among various customer categories in the last 5 years.

Table 2.2 Consumption in GWh among various categories 2014/15-2018/19

types of customers covered by this tariff	**sales in GWh**				
	2014/15	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Domestic (DC)	1,866	2,007	2,138	2,335	2366
Small Commercial (SC)	1,143	1,153	1,201 0	1,222	1250
Commercial and Industrial (CI)	4,030	4,104	4,266	4,225	4462
Off-peak (IT)	15	26	41	33	N/A
Street lighting (SL)	35	40	55	66	68
REP System (DC(*((DC,SC,SL)	525	537	549	554	595
Export to Uganda	38	43	20	22	27
Export to Tanesco	2	2	2	1	0.01
Total	**7,655**	**7,912**	**8,272**	**8,459**	**8,769**
Annual increase rate (%)	**5.70**	**3.40**	**4.50**	**2.30**	**3.70**

Source: Kenya Power and lighting Company

Note: the words in the parentheses indicates tariff's name.

The electricity consumption by the regions is illustrated in Table 2.3.

Table 2.3. Consumption in GWh by Region

REGION	2014/15	2015/16	2016/17	2017/18	2018/19
Nairobi North	1,032	1,187	1,301	1,204	1,219
Nairobi South	1,667	1,696	1,759	1,728	1,719
Nairobi West	1,059	808	853	898	958
Coast	1,312	1,338	1,389	1,435	1,477
Central Rift	456	569	596	650	689
North Rift	269	280	269	303	288
South Nyanza	0	48	86	88	104
West Kenya	525	320	313	361	376
Mt Kenya	309	413	431	437	456
North Eastern	461	671	704	776	862
KPLC Sales	**7,090**	**7,330**	**7,701**	**7,881**	**8,147**
R.E.P. Schemes	525	537	549	554	595
Export Sales	40	45	22	23	27
Total	**7,655**	**7,912**	**8,272**	**8,459**	**8,769**
Annual increase rate (%)	**5.7%**	**3.4%**	**4.5%**	**2.3%**	**3.7%**

Source: Kenya Power and lighting Company

The consumption growth seen is mostly driven by the expansion of the economy and factors like: Population growth; urbanization; accelerated electrification programs and progressive growth in the agricultural, manufacturing and other sectors that drive GDP growth.

2.6.4. *Transmission and Distribution*

In the fiscal year 2018/2019, the total length of the transmission and distribution network was 236,134 kilometers for all voltage levels compared to 59,322 kilometers in 2014/15. This is a significant annual average growth of 9.92%. This growth has been accelerated by the development of transmission infrastructure by Kenya Electricity Transmission Company (KETRACO). The transmission line capacities are 132 kV, 220 kV and 400 kV, as shown in Figure 2.4.

Table 2.4. Transmission and Distribution Line Lengths between FY 2014/15-2018/19

VOLTAGE	2014/15	2015/16	2016/17	2017/18	2018/19
400 kV			96.8	1,244.4	2,116.4
220 kV	1,352	1,452	1,555	1,686	1,686
132 kV	2,824	3,087	3,208	3,322	3,372
66 kV	952	977	1,000	1,168	1,187
33 kV	21,370	27,497	30,846	34,508	35,177
11 kV	32,823	35,383	37,234	38,968	39,797
Total HV and MV	59,322	68,396	73,940	80,897	83,335
415/240V or 433/250V		110,778	139,642	143,331	152,799
Total	**59,322**	**179,174**	**213,582**	**224,228**	**236,134**
Annual increase rate (%)	**4.8**	**15.3**	**19.2**	**5**	**5**

Source: Kenya Power and lighting Company

The aggregate transmission network was 7,174.35 km by June 2019. The national electricity distribution network is managed by KPLC and is placed at 228,960 km in 2018/19. The national distribution network is made up of 66 kV feeder lines, 33 kV and 11 kV medium-voltage lines and 415/240 V low voltage lines spread across the country. To attain universal access by 2022, the country has set out plans to construct more distribution lines and substations to expand the power supply in rural areas. Various programs and projects have also been undertaken to reduce system losses and upgrade system reliability.

Figure 2.4. Transmission Network in Kenya, 2019

Source: KETRACO (*Transmission Network in Kenya, 2019*)

Substations have also seen an increase in generation under the review period, from 3,025 MVA in 2015 to 3,720 MVA in 2019. Transmission substations have also recorded an increase in the same period from 3,144 MVA to 4,942 MVA, while distribution substations, which take electricity from the main lines for distribution to end consumers, rose from 3,572 MVA in 2014/15 to 4,480 MVA in FY 2018/19. There is a substantial capacity increase from the distribution transformer in the same study period from 6,384 MVA to 7,844 MVA. Table 4 represents the transmission and distribution substations capacities between 2015 and 2019.

Table 2.5. Transformers in Service, total installed capacity in MVA as at 30th June, 2019

	2014/15	2015/16	2016/17	2017/18	2018/19
Generation Substations Total	3025	3145	3205	3370	3720
Transmission Substations Total	3144	3704	4376	4866	4942
Distribution Substations Total	3572	3848	4056	4372	4480
11/0.415 kV & 33/0.415 kV Distribution Transformers	6,384	7,088	7,276	7,606	7,844

Source: Kenya Power and lighting Company

2.7. Natural Energy Resources in Kenya

This section considers sources of energy that can be used to generate electric power, along with the planned and potential sources of energy for future electricity generation in the country. Emphasis is given to the infrastructure and future development of different energy sources.

2.7.1. *Fossil Energy Sources*

This source consists of crude oil, heavy fuel oil, gasoil and kerosene.

i. **Crude oil**: According to the Least Cost Power Development Plan, LCPDP (2019–2039), Kenya uses some petroleum products, such as gas, oil and heavy fuel oils, for power generation. The country also has about 46 onshore and offshore exploration blocks across the country and off the coast and a total of 43 exploratory wells, which have been drilled in four basins. For quite some time, the power sector has depended on petrol-thermal generation. This dependence has, however, been on the decline as the country has been exploring renewable sources of energy (Energy & Petroleum, 2015).

ii. **Heavy fuel oil (HFO)** is mostly used in diesel power plants like the Kipevu Power Station in Mombasa, while the remaining portion is used in industries for production. This fuel option is, however, not recommended for electricity generation because of its negative environmental impact.

iii. **Gasoil and kerosene** are used as a generation fuel. Kerosene is used in households for lighting and generators and in gas turbines in power stations like the Muhoroni Power Station. The transportation sector, however, accounts for a sizeable share of the aggregate gasoil consumption in the country. These fuel options are mostly recommended for backup and peak capacity plants.

2.7.2. *Solid Fuels*

Coal reserves have been found in the Mui Basin that passes across the Kitui county 200 km east of Nairobi. The reserve covers an area of about 500 square kilometers and is split into four blocks: A (Zombe – Kabati), B (Itiku – Mutitu), C (Yoonye – Kateiko) and D (Isekele – Karunga. The reserve has an estimated depth of 27 meters with 400 million tons of coal reserves confirmed in Block C109. The government has already awarded a contract for mining. This coal is an important fuel option because the government is planning to commission a coal power plant in Lamu.

2.7.3. *Renewable Energy Sources*

The country has a wealth of potential power generation from renewable energy sources. The abundance of hydro, solar, wind, geothermal and biomass resources has encouraged the government to develop programs to expand the renewable energy generation resources in the country.

i. **Geothermal energy.** Kenya has an estimated 1000 MW of geothermal resource in the Rift Valley area, spread over 14 sites. Presently, geothermal capacity provides almost 50% of total power generation, having an installed capacity of 828 MW. New reservoirs are under exploration in Suswa, Longonot, Akiira, and Baringo Silali for the medium and long term. Geothermal power is expected to play an important role in the Kenyan power system in the future, and due to its low short-run marginal costs, it primarily operates as a base load. Expertise in and adequate knowledge of geothermal technology implementation, exploration, drilling, and operation already exists in the country. The Geothermal Development Company (GDC), which is a state-owned company, is tasked with the rapid development of geothermal resources in the country through surface exploration and drilling for steam.

ii. **Hydropower**. Kenya has hydropower potential estimated to be in the range of 3,000–6,000 MW, which is a considerable amount. About 800 MW is already tapped by KenGen, mainly in a large installation. The current hydropower installations contribute about 30% of the total national annual electricity generation. Almost half of the total potential comes from small rivers. The introduction of the feed-in tariff policy in 2008 has accelerated the development of these small-scale candidate sites across the country, with the majority being managed by the Kenya Tea Development Authority (KTDA). The potential hydropower sites are located in five geographical areas, mainly in the major drainage basins, as shown in Table 2.6.

Table 2.6. Potential hydropower sites

Catchment area	Identified Hydropower potential (MW)
Lake Victoria basin	329
Rift Valley basin	305
Athi River basin	60
Tana River basin	790
Total	**1,484**

Source: Least cost power development plan (2019-2039)

iii. **Wind energy.** In terms of commercial development, wind power technology is one of the most developed renewable energy technologies. Kenya has a huge potential for wind power. Recently, the country invested in a 25.5 MW wind farm in Ngong constituting thirty 850 kW turbines. In addition, Lake Turkana Wind Power (LTWP) runs a 310 MW plant in Loiyangalani comprising 365 turbines of 850 kW each. Some of the best wind sites in the country are located in Samburu, Marsabit, Meru, Laikipia, Nyeri, Samburu, Nyandarua and Kajiado counties. In total, the country has about 90,000 square kilometers of space with first-rate wind speeds of 6 m/s and higher. Wind turbines generate electricity intermittently depending on the wind speed, which fluctuates from time to time, making their capacity factors between 20 to 55%. The country has wind potential of up to 4,600 MW according to a wind energy data analysis and development program done in 2013 by Wind Force Management Services Pvt. Ltd.

iv. **Solar Energy Resources**. Because Kenya is located near the equator, with an average daily insolation of 4–6 kWh/m^2 and an average of 5–7 peak sunshine hours, 10–14% of the energy can be converted into electricity, based on the dispersion and conversion efficiency of PV modules. The government has also enhanced support for this technology as solar plays an important role in rural electrification. Approximately 200,000 photovoltaic solar home systems, mostly rated between 10 We and 20 We at an approximate cost of KES 1,000/We, are presently in use in the country and generate about 9 GWh of electricity yearly, mainly used for lighting and powering electronics. This coverage, at 1.2%, is still a fraction of the households in the country. With government support, the penetration is expected to rise, given that four million households in rural areas need to be electrified.

v. **Biomass, biogas, and waste-to-energy** is a form of energy that usually comes from sources like agricultural crops and residues, animal and human wastes, wood and wood residues, and agricultural crops and residues. This source of energy is influenced by the demand side, and its conversion depends on the biomass itself, with a final result of electricity, direct heat, liquid, and a solid or gaseous fuel. This flexibility is one advantage this source of energy has over other renewable sources of energy. Many technologies are commercially available for the conversion process, and the resulting energy can be used in heating or power generation. Cogeneration can combine heating and power electricity generation, and solid biomass can be used in an incinerator because it is rich in lignin. The released flue gas produces electricity and heat, and in gaseous form, it provides syngas.

Biomass is a combination of methane and carbon dioxide and other gases in small quantities and, consequently, needs additional cleaning before it can be used because of its components that are heterogeneous in nature. Municipal solid wastes (MSW) are a potential source of biomass material and energy. The wastes should be collected separately by source to collect and recycle as much as possible. Currently, two sugar mills in Kenya, Mumias and Kwale, are using biomass as a source of power. A study carried out in 2010 by GTZ, an energy development consultant, indicates the potential of biogas energy, primarily for heating and, to a lesser extent, for power production. Some of the projects have been presented to the FIT scheme. With the development of the agricultural industry and the revamping of sugar mills, it is expected that there will be an increase in this form of energy.

2.7.4. *Other Energy Sources*

Apart from the indigenous sources of energy as the main power generators, some regional interconnections could reduce the demand for power generation. Kenya is also exploring the application of nuclear energy for power generation.

i. **Nuclear Power**. The rising awareness of the advantages of nuclear power, such as mitigation of climate change and energy security, has made several countries, including Kenya, develop an interest in nuclear power for electricity production. At present, only low levels of uranium oxide have been found in Kenya. Nevertheless, the exploration of uranium is still ongoing. Nuclear power accounts for 12% of the world electricity generation, which is 2563 TWh in 2018. The total recoverable uranium reserves in the world are estimated at 6.14 million tonnes in 2017. This amount of uranium could last for more than 130 years.

ii. **Interconnections with Neighboring Countries**. Presently, the Kenya national grid is interconnected with Uganda via a 132 kV transmission line and with nearby countries via distribution lines. These connections provide mutual support and system stability and also power isolated areas near the borders. The goal of this project is to increase transfer capacities, grid flexibility in operations, and boost the sustainable electricity supply.

iii. **Eastern African Power Pool:** The Eastern African Power Pool (EAPP) was established in 2005 as an intergovernmental organization whose objective is to provide an effective model for bringing together electricity resources and promote power exchanges in the region. The Regional Power System Master Plan and Grid Code Study, which was promulgated in 2011, shows that major projects have been identified and also criteria to support this inter-regional power exchange and a phased interconnection plan has been developed. Three interconnection projects are already being implemented between Kenya and regional countries, and several projects are in the planning stages. Already ten countries have signed up for EAPP: The Democratic Republic of the Congo, Burundi, Ethiopia, Kenya, Egypt, Libya, Sudan, Rwanda, Uganda, and Tanzania.

iv. **Interconnection with Ethiopia.** The building of the high voltage direct current (HVDC) overhead transmission line between Kenya and Ethiopia is underway, and completion was expected by April 2020. The construction of a 500 kV line runs from Welayta Sodo in Ethiopia to Suswa in Kenya with an approximate length of 1,045 km, of which 433 km is in Ethiopia, and 612 km is in Kenya. The line will transfer 2 GW of electricity because it is a bipolar configuration line. This interconnection will be operated by the Ethiopian Electric Power from Ethiopia and by Kenya Electricity Transmission Co. Ltd. from Kenya.

v. **Interconnection with Uganda**. A 400 kV line interconnection is planned between Kenya, Rwanda, and Uganda to boost the power trade in the region. The interconnector between Uganda and Kenya is already being constructed. A 400 kV double circuit overhead line is being constructed from Tororo in Uganda to Lessos in Kenya. The design capacity of this line is 1,700 MW.

vi. **Interconnection with Tanzania**. A double circuit transmission line of 400 kV, 507.5 km in length, is under construction between Kenya and Tanzania. 93 km of this line will be in Kenya, and the remaining 415 km will be in Tanzania. The interconnection line is designed for a capacity of 1,700 MW. The purpose of this line is to boost the power exchange market within EAPP and the Southern Africa Power Pool (SAPP) through Zambia.

Chapter 3

Theoretical Background

3.1. Energy Security Background

The integral position of energy in the development of the world's economies has made energy security a global interest. With modernization and population increase, energy usage has increased rapidly, and people's livelihoods and national economies have become dependent on energy usage. The concept of energy security gained attention in the 1970s in the wake of the first oil crisis when oil prices escalated.

Oil-importing countries struggled to sustain their economies as they were caught off guard amidst the high oil prices. Several policies were adopted to salvage the situation. As oil prices fell in the 1980s, the attention shifted to market reforms and restructuring, and little focus was paid to energy security concerns. This situation continued until the episode of peak oil and the demand to establish a domestic supply capacity to meet the increasing need arose. Therefore, the resurfacing of the energy security issue is attributed to sustained high oil prices.

3.2. Energy Security Definition

Mahmood & Ayaz (2018) define energy security as a "reliable and suitable supply of energy at reasonable prices." The reliability and suitability of supply indicate the uninterrupted supply of energy with a view to satisfying its demand. The most important concern of energy security is linked with the availability of sufficient supply that is steady and at an affordable price to satisfy demand in the future. (Chuang & Ma, 2013) Chuang and Ma (2013) define energy security as the "potentiality of an economy to assure the availability of the energy resource supply in a timely and sustainable manner, with energy prices at a rate that will not unfavorably affect the performance of the economy."

The International Energy Agency (IEA) (2017) defines energy security as an uninterrupted availability of energy supply at an affordable price. This definition focuses on the affordability, accessibility, and availability of energy as pivotal to energy security. (Erahman, Purwanto, Sudibandriyo, & Hidayatno, 2016) Erahman, Purwanto, Sudibandriyo, and Hidayantno (2016) define energy security as "technical feasibility, affordability, reliability, environmental protection, and security of supply." These definitions show that there is no absolute definition of energy security. As a consequence, the definition of energy security depends on the perspective of each country.

Based on the similarities in the definitions suggested above, I will simply define energy security as the assurance of an uninterrupted supply of energy at an affordable price while respecting environmental concerns. Including environmental concerns in the definition is important because climate change can affect the continuous availability of energy, thereby affecting the country's energy security (Olawale, Owolabi, Oyedele, Owolabi, & Akinade, 2017).

3.2. Energy security dimensions

Energy security can be described through a set of indicators from several studies. The dimensions offer different perspectives to better explain energy security. The concept of the four As (availability, accessibility, affordability and acceptability) dominates energy security studies (Kruyt, van Vuuren, de Vries, & Groenenberg, 2009; Erahman et al., 2016; Kruyt et al., 2009). We can conclude with certainty that the basic concept of energy security has these four dimensions. Additional dimensions have been added to include energy efficiency and environmental sustainability (Sovacool & Mukherjee, 2011). (Ang, Choong, & Ng, 2015) Ang, Choong, and Ng (2015) view energy security as comprised of seven dimensions: availability, energy prices, infrastructure, societal effects, environment, efficiency, and governance. The difference between their concept and the four As is the additional three dimensions of governance, societal effects, and efficiency.

Energy security dimensions can be categorized into six groups: affordability, availability, accessibility, efficiency, acceptability, and governance. Governance may be thought to have the smallest value as a dimension, and so it will not be included in the energy security analysis. In addition, governance is not included due to the limitation of data: a major part of the needed data in this dimension is qualitative and inaccessible. Therefore, including governance as a dimension in the study will give a less coherent analysis. Every country has a different measurement criterion for collecting data about governance. Hence, this study will only focus on five dimensions, as shown in Table 3.1.

Table 3.1. Definition of energy security dimensions

Dimension	Definitions
Availability	Having sufficient energy supplies from domestic resources, this can be done by promoting energy production, diversification of energy resources and having final energy adequacy.
Affordability	Having final energy at low cost and at an affordable rate to the local economy.
Accessibility	Having sufficient access to commercial energy by the local economy to promote a balanced society.
Acceptability	This is to decrease global warming impact.
Efficiency	Having less energy consumption for the same service and reduced energy loss up to the end user.

Source: Erahman et al., (2016)

3.2.1. *Energy Security in Terms of Availability*

Kruyt et al. (2009) argued that the availability indicator encompasses resource estimates that can be classified and quantified. The amount of all available resources in a particular country incorporates the total estimation of its resources (Narula, Reddy, Pachauri, & Dev, 2017). The availability dimension matrix includes both short- and long-term facets of physical energy security. Total primary energy supply per capita (TPESP) measures the extent of per capita supply. This analysis uses energy supply rather than energy production to explain the country's potential in terms of domestic energy supply (Erahman et al., 2016). Dependency (or self-sufficiency, SS) is the capability of the domestic energy production to meet energy needs; this matrix evaluates the ratio between domestic energy production and demand (Martchamadol & Kumar, 2014; Sharifuddin, 2014; Sovacool, Mukherjee, Drupady, & D'Agostino, 2011; Sovacool, 2013; Martchamadol & Kumar, 2013). Diversification of the sources of the total primary energy supply (TPES) is important because energy sources have different attributes in terms of availability. These attributes may depend on price, ease of trading, and burden to the environment. No one energy resource excels in all the components. Each characteristic needs to be used thoughtfully. As it is salient to come up with a well-balanced energy mix, that is to say, by diversifying sources of energy, the advantage of each source of energy can be tapped while at the same time reducing the risks and disadvantages of each source (Koyama & Kutani).

HHI has been adopted as a measure of diversity for this study.

HHI: Hirschman-Herfindahl Index (Eq.3.1)

$$HHH=\sum_{i=1}^{N} S_i^2 \qquad (3.1)$$

Where: S_i is the market share of firm in the market

N is the number of firms

HHI is the sum of the squares of the individual market shares of every firm in the market. Higher weight on higher proportion, higher value means more concentration and the measurements are between 0-1.

3.2.2. *Energy Security in Terms of Accessibility*

This dimension analyzes the country's ability to secure energy sources within the country and outside the country (Ren & Sovacool, 2014). This dimension consists of the electrification ratio indicator, which is access to electricity as a percentage of the population (Sharifuddin, 2014). It shows the number of households with access to electricity. This indicator fosters independently developed energy resources like renewable energies to reflect the country's effort in making sure all the households, even in remote parts of the country, are connected to energy resources (Budiarso et al., 2015). Kenya has launched a universal rural electrification project to make sure as many people as possible are connected to power (Abdullah & Markandya, 2012).

Another indicator in the accessibility category is human resources for nuclear energy. This indicator shows the number of human resources required for the continuous nuclear industries development. This issue came about after the Fukushima accident, so this indicator is key for the accessibility dimension (Tanigawa, Hosoi, Hirohashi, Iwasaki, & Kamiya, 2012; Baba, 2013).

3.2.3. *Energy Security in Terms of Affordability*

This indicator is simply the cost of energy inflow determined by the energy prices for industries and households and mirrors the country's economic situation. IEA's definition of energy security reflects the availability of energy inflow at an affordable price. The less expensive an energy inflow is, the more affordable it is considered to be. The price considered in this indicator is the "price paid for a unit of energy" (Boardman, 2013). When the cost of energy is increased, the affordability decreases, leading to a regression in energy security, while decreasing prices can be seen as an increase in affordability, signifying an increase in energy security (Boardman, 2013). This dimension comprises the following indicators: a) Fuel cost of electric companies shows the costs to electric companies of importing fuels for electricity generation and how dependent a country is on the imported fuels, b) Electricity price shows the amount charged to industries and households to use electricity (Sovacool, 2012).

3.2.4. *Energy Security in Terms of Acceptability*

This indicator is based on the IEA's definition of energy security, which refers to respecting environmental concerns. This indicator evaluates the technology adopted by other indicators in the analysis of energy security. The technology used in energy production should be less harmful to the environment and should meet all the permitted environmental requirements set by the regulatory agencies (Prambudia & Nakano, 2012). This study analyses the acceptability dimension with indicators that relate to the environment and social issues which emanate from the production and consumption of energy (Sharifuddin, 2014; Wyman, 2013). Consumption of fossil fuels: this indicator directly links to CO_2 emission, which adversely affects the global environment. It also shows the energy mix of a nation (Selvakkumaran & Limmeechokchai, 2013).

CO_2 emission from energy sources: this indicator is commonly used in the measurement of global environmental impact coming from the use of energy (Sharifuddin, 2014). Radioactive waste: this indicator mirrors the extent to which a nation makes an effort in the disposal of radioactive wastes materials without adversely contaminating the environment and human health. This indicator is greatly influenced by the (Tanigawa et al., 2012) supporting ratio for nuclear energy, which is an indicator that mirrors the public opinion, support or attitude about nuclear energy. Following the Fukushima accident, this indicator became a critical part of the acceptability dimension (Kim, Kim, & Kim, 2013; Visschers & Wallquist, 2013).

3.2.5. *Energy Security in Terms of Efficiency*

This dimension shows the extent of the efficiency of energy consumption. It primarily influences the demand management side of energy consumption. Two indicators can be applied to analyze this dimension. Energy intensity is an indicator that mirrors the relationship between energy consumption and GDP to show the utilization rate for energy. This relationship can also be affected by the economic structure of a country. For instance, the ratio of a nation's energy consumption to its GDP varies among countries that, for example, focus their economy on energy-intensive industries like the production of steel compared to nations that focus on the financial sector. Power distribution losses is an indicator that shows that the system should have a lower degree of energy loss during distribution and transmission as more losses mean lower efficiency in the energy network.

Table. 3.2. Summary of current studies on energy security

Author	Dimension	Study findings
Paravantis & Kontoulis, (2020)	Proposes a novel energy security index with the following dimensions: i. Physical availability, ii. Technology development, iii. Economic affordability, iv. Social accessibility, v. Governance, vi. Unconventional threats vii. Natural environment.	Physical availability followed by technology development, economic affordability, and governance were rate as the most important. Whereas, natural environment was rated as the least important by the panel of experts**.**
Sharifuddin, (2014)	Conceptualizes energy security as having 5 core dimensions: i. Availability, ii. Stability, iii. Affordability, iv. Efficiency, and	The 35 indicators have been subdivided into 13 elements and five elements of energy security. The indicator score is synthesized through normalization into scores of

Author	Dimension	Study findings
	v. Environmental impact	elements, main aspects and ESI which acts as the reference index for discussion. Biggest deterioration in ESI occur in the aspect of stability followed by environment.
Rogers-Hayden, Hatton, & Lorenzoni, (2011)	Stakeholder interviews	Energy security is an important factor to improve efficiency, effectiveness and reliability of power. Need for nuclear new build to reduce energy demand and increase energy supply.
Ates, (2015)	This study focuses on the three objectives to energy efficiency, which are: i. Energy Demand ii. Cost Curve Emission Curve	Energy management and its standardization are some of the crucial ways to increasing energy efficiency and combating climate change as this decreases the cost of energy and CO2 emission.
Nawaz & Alvi, (2018)	Employs economic analysis on: i. energy insecurity (EINS), ii. socio-economic condition (SEC) and iii. Environment (ENV)	To increase energy security. Pakistan should focus on less reliance on imported fuel products and need to shift its focus on indigenous energy resources.
Kucharski & Unesaki (2016)	Focuses on low carbon and energy mix	Dependence on foreign resources makes the energy sector of Japan fragile and exposed various risks. Therefore, needs to explore the non-conventional and renewable energy options
Brown & Huntington, (2008)	Focuses on policy tradeoff: Assuming each energy-conserving and alternative-fuel technology has different attributes in improving energy security and abating greenhouse gas emissions	The use of a specific alternative energy or energy conservation technology can improve energy security, protect against the accumulation of greenhouse gases, or provide a combination of these two policy goals.

Author	Dimension	Study findings
APERC, (2007)	Focuses on the 4As of energy security: i. Availability: which refers to the availability of fossil fuels and nuclear energy; ii. Affordability of fuel price and energy infrastructure, iii. Accessibility looks at the barriers to accessing the energy resources; and iv. Acceptability: deals with the intensity of CO_2 emission and how to mitigate it.	Achieving energy security needs a wholistic framework approach.
Sovacool & Mukherjee, (2011)	Redeveloped APERC's 4As in five dimensions: i. Availability, ii. Affordability, iii. Sustainability, iv. Technology v. Development, and Regulation	strongly suggest that energy security is a multidimensional phenomenon comprising: Energy reserves and stock-piles, fuel mixes and diversification, justice and equity, price stability and affordability, technology development, energy efficiency, environmental quality, resilience, investment, governance, and regulation all influence energy and therefore, form part of the contemporary national energy security concern.
Sovacool & Brown, (2010)	Examines energy security in 4 dimensions: i. Availability, ii. Affordability, iii. Energy and economic efficiency, and iv. Environmental stewardship.	Lack of standardized set of metrics, results in difficulty in determining the extent to which economies are properly responding to the emerging energy security challenges related to climate change.
Vivoda, (2010)	Furthering the findings of Von Hippel et al. by increasing the dimensions to 5: i. Demand management, ii. Efficiency, iii. Human security, iv. International, and	Based on an expanded conceptualization of energy security: offered a corrective to the narrow and outdated conceptualization of energy security.

Author	Dimension	Study findings
	v.Policy.	

3.3. Contribution and Gap

Although there is an extensive literature review on energy security, there is as yet no study that evaluates energy security measures and responds to climate change simultaneously using the energy security index model in Kenya. Therefore, this research will contribute to helping the policy makers and energy planners formulate informed policies and strategies to ensure energy security in the country. This contribution is also in line with improving prior useful methodologies.

Chapter 4

Methodology and Data

4.1. Energy Security Model Conceptualization

4.1.1. *Data*

Historical data from 1990 to 2017 was used in evaluating Kenya‘s energy security and response to climate change focusing on the electricity industry in Kenya. Subsequently, a comparative analysis of Ethiopia and Tanzania was conducted. Table 4.1 illustrates the data and their sources.

Table 4.1. Data definition and sources

Variable	Definition	source
TDL	Electric power transmission and distribution losses (% of output)	World Bank
GDP	GDP ($constant 2010)	
Pop	Population (People)	
CO_2	CO_2 emissions	
AE	Access to electricity (% of population)	
TFEC	Total Final Energy Consumption (t)	IEA
FOC	Fossil Fuel Consumption	
TPES	Total Primary Energy Supply (Ktone)	
TPEP	Total Primary Energy Production (Ktone)	
DP	Domestic Production (Ktone)	
TPEC	Total Primary Electricity Consumption	
ELP	Electricity Production	

4.1.2. *Establishing Dimensions and Indicators*

The approach to energy security is established through concept gathering from different literature reviews. Then, duplicate dimensions are removed, and only the aspects with available data that can befit the Kenyan scenario are combined (Erahman et al., 2016). The dimensions considered are availability, accessibility, acceptability and, lastly, energy efficiency. These are the most frequently used dimensions, although this study modified some dimensions from their existing source. Sub-dimension indices can help us better understand and evaluate the significance of energy security for the implementation of energy policies and plans. They are collaborative variables used to evaluate long-term energy supply security. The dimensions and related indicators discussed in this study are listed in Table 4.2.

Table 4.2. Energy indicators

Dimension	Indicator	Equation	Impact
Availability	Supply Security	$SS=\frac{TPES}{POP}$	+
	Diversification in Electricity	$H=\sum_{i=1}^{N} S_1^N$	+
	Self-sufficiency	$SS=\frac{TPES}{TPEC}$	+
Accessibility	Access to electricity (% of population)	CO_2	+
	Electricity consumption per capita	$ECP=\frac{EP}{POP}$	+
Acceptability	Emission Intensity (Energy-wise)	$C=\frac{CO2}{TPEC}$	–
	Emission Intensity (Economy wise)	$C=\frac{CO2}{GDP}$	–
	Emission Intensity (Population Wise)	$C=\frac{CO2}{POP}$	–
Energy Efficiency	Energy Intensity	$EI=\frac{TPEC}{GDP}$	–
	Power distribution losses	$PDL=\frac{EDL}{ELP}$	–

Source: Erahman et al., (2016)

i. **Availability** measures the sufficiency of the energy supply from domestic production; it also measures other factors like the security of supply and the diversification of the energy mix in a country. These factors are combined to ensure the energy is adequate to sustain the country's economy because the country depends on energy to develop and meet its agendas.
ii. **Accessibility** reflects the need to have sufficient access to commercial energy to promote a balanced and equal society.
iii. **Acceptability** reflects the need to minimize the impact of global warming, especially from the energy sector. The lower the emissions, the more secure an economy is considered to be in regard to energy security. Emissions are considered to emanate from energy consumption, GDP growth, and population growth.
iv. **Efficiency** dimension reflects the minimum utilization of energy for the same service and minimization of energy loss from the transmission to the end user. This can be regulated by the adoption of advanced technology and utilizing products that contribute to higher efficiency.

Supply security: the supply of energy should be reliable and plentiful. This comprises the availability of the total primary energy supply per capita. The availability within a competitive framework also reduces dependence on one or two sources of energy.

Diversification in electricity: this indicator measures the diversity of the primary fuel used to generate electricity. This indicator identifies three main attributes:

i. Variety: this is the portions into which the capacity in question can be apportioned.

ii. Balance: patterns in the appropriation of the energy capacity across identified groups.

iii. Disparity: the degree and nature to which the groups vary from each other.

For this study Herfindahl Hirschman Index (HHH) was applied as Equation (4.1).

$$HHH=\sum_{i=1}^{n} P_I^2 \qquad (4.1)$$

Where: S_i is the market share of firm in the market

N is the number of firms

Self-security: This is the share of energy consumption over domestic energy production, it measures the country's energy security strength in terms of availability of domestic resources, notwithstanding whether the energy type is fossil or renewable energy.

Emission intensity: this indicator measures CO_2 emission intensity from; energy sector CO_2 emission per capita, the intensity that comes from energy sector CO_2 emission per unit of final energy consumption and lastly emission that is attributed to population growth.

Energy Intensity: this is the measure of energy of domestic energy consumption per GDP. This indicator shows the relationship between the energy consumption and the economic growth.

4.2. Energy Security Index Model

Constructing the energy security index model needs to take three steps, called indicator's value calculation, normalization, and evaluation.

i. **Calculating the indicators' value.** The value of each matrix is calculated at this step using their related formulas, as shown in the table above. Standardization is done to allow synthesis of the results from the multiple indicators, each with its unit.

ii. **Normalization.** This is done to all the scores or sets of scores because each score has a different scale. For ease of comparison, the data is normalized by scaling them between 0 and 1, where 0 characterizes the worst performance, and 1 characterizes the best performance. The normalization formula is shown in Eq 4.2.

$$NI_j = \frac{I_j - I_{min}}{I_{max} - I_{min}} \tag{4.2}$$

Where,

NI_j = Normalized indicator I_j

I_j = Indicator I_j

I_{min} =Lowest value of indicator I

I_{max}= highest value of indicator I

iii. **Evaluation.** Some indicators show better results when lower, such as emission intensity, energy intensity and power distribution and losses. For supply security, diversification self-sufficiency, access to electricity and electricity consumption per capita, the higher the score, the better. The results have been transformed where necessary so that all can be shown on similar charts.

Chapter 5

Results and Analysis

5.1. Energy Security Dimensions in Kenya

This section summarizes the interpretation of results in the dimensions, and the sub-indicator then ranks all the dimensions and sub-indicators by way of comparative analysis.

Availability. This dimension has a slightly increasing trend with the high points in Part 1, 3 and 5 with maximum values of 0.4242, 0.4117 and 0.3964 in 1994, 2004, and 2014, respectively. The lowest points are 0.1432, 0.1379, and 0.2295 in 2000, 2010, and 2016, respectively. This dimension is represented by three indicators: supply security, energy diversification, and self-sufficiency. The fluctuation in the trend results from the effect of these three indicators (Figure 5.1).

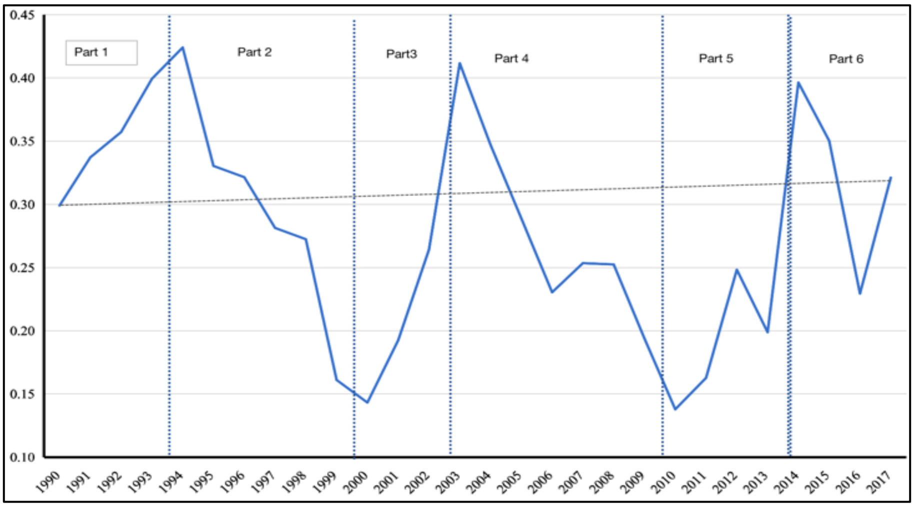

Figure 5.1. Energy Security Availability in Kenya

Accessibility. This dimension has an increasing trend over time. This signifies an increase in the sub-indicators, electric consumption per capita and electrification ratio. The lowest values, 0.0639 and 0.1035, are in 1994 and 2000, respectively, and can be attributed to a reduction in GDP in the dry seasons. The increase in the trend is due to an increase in the exploitation of renewable resources in that country (Figure 5.2).

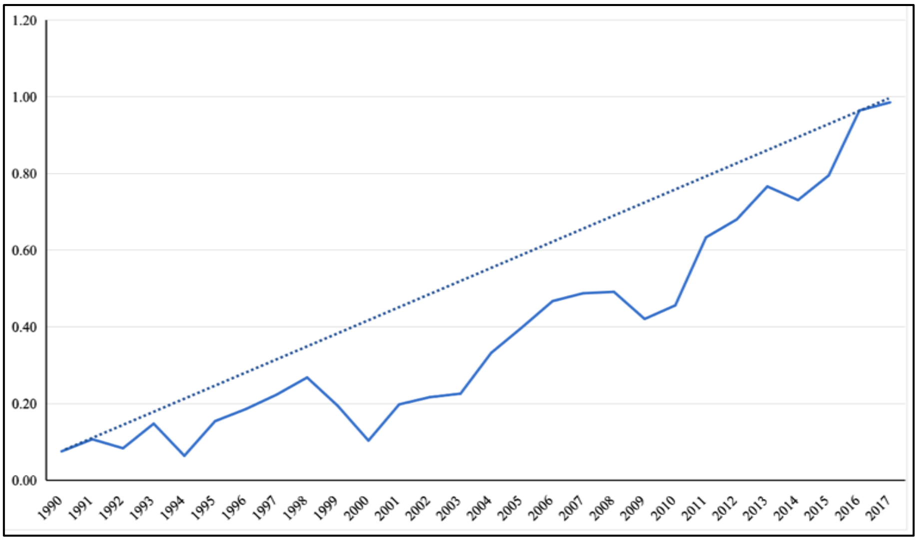

Figure 5.2. Energy Security Accessibility in Kenya

Acceptability. This dimension is increasing but not exponentially. Sharp increases can be observed in 2000 and 2016 at 0.718 and 0.989, respectively. The lowest values are seen in 2003 and 2013, at 0.00 and 0.390, respectively. The higher values show more emissions, which is not good, and the lower values show lower emission intensity (Figure 5.3).

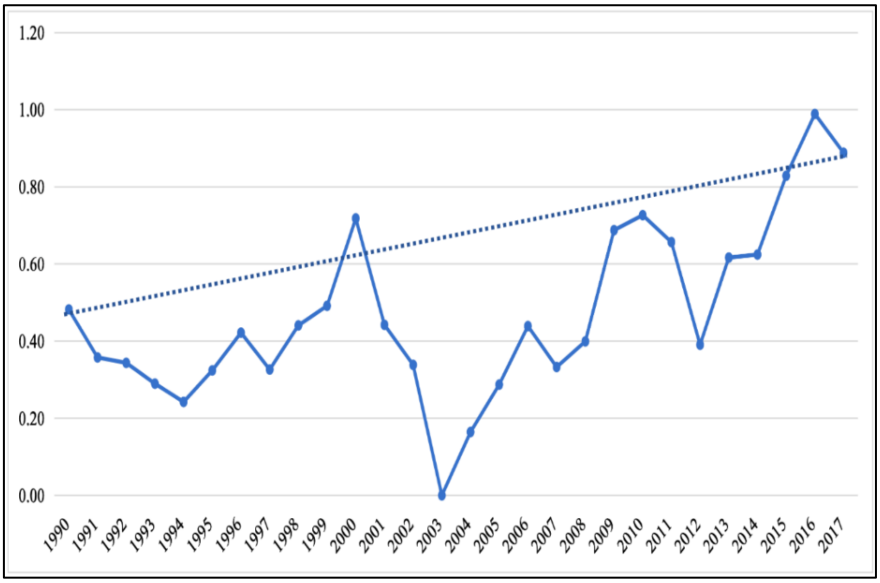

Figure 5.3. Energy Security Acceptability in Kenya

Energy Efficiency. The dimension is increasing in the first phase between 1991– 2002, showing the worsening of energy efficiency. The lowest values are in the last phase, between 2002– 2017, which shows better efficiency. This shows a positive relationship between energy consumption and economic growth in Kenya (Figure 5.4).

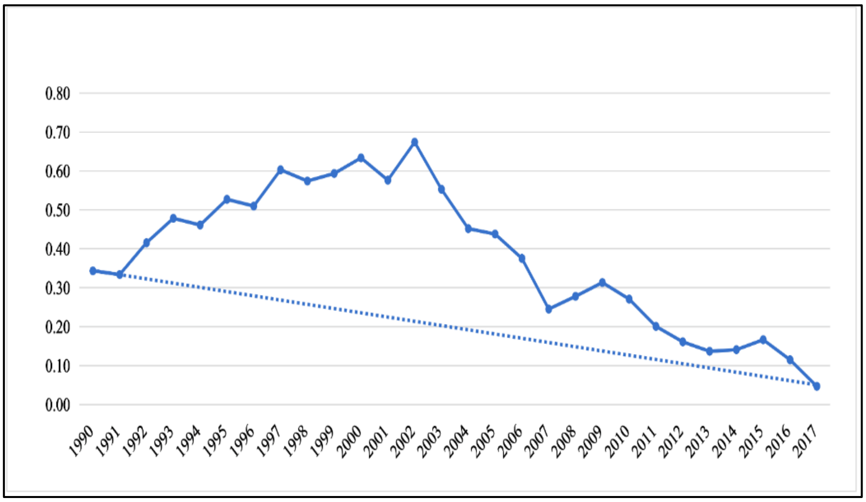

Figure 5.4. Energy Efficiency in Kenya

5.2. Comparative Analysis of Energy Security Dimensions and Indicators.

This section compares the results of the dimensions and indicators for the selected East African countries then ranks their performance.

5.2.1. *Energy Availability*

In the **Kenyan** case, this dimension has been divided into six parts. Parts 1, 3, and 5 show an increasing trend in availability, while Parts 2, 4, and 6 show a decreasing trend. Parts 2 and 4 are declining because of the severe drought of 1998/99 and 2003/2004, the high capital cost for electricity access, and the prevailing economic recession. In the fiscal year 1998/99, the overall demand for electricity stood at 4,637 GWh but declined to 4,081 GWh at the apex of the drought in 2000. Since then, the growth has been delayed by the slow economic recovery. Parts 1, 3, and 5 are increasing due to the economic recovery and the growth in electricity demand based on annual GDP growth (Sessional Paper 4 on Energy 2004). The lifting of donor aid embargo to the power sector in the late 1990s and the significant reforms that were affected by liberalizing power generation allowed the independent power producers (IPPs) to broaden the resources for the expansion of the generation system and diversify the energy resources (Tigabu et al., 2017).

Ethiopia

The score for this dimension does not fluctuate very much over the study period. The score generally reaches its peak in 2006, 2010, and 2011 for Parts 1 and 2. This dimension reaches its lowest score in 2008 and part of 2019. The “total primary energy supply per capita” and the diversification increased over this period because Ethiopia explored more renewables. The lowest score in 2008 and part of 2019 was experienced due to the drought in Ethiopia, which affected hydropower.

Tanzania

This dimension shows a decreasing trend over the years, and a steady decrease can be observed in Parts 1, 3 and 5. This decrease is due to a decrease in self-sufficiency between the periods due to the recurring drought in 2009/2010, 2010/2011, and 2011/2012. The drought led to reduced reserve capacity. Reduced use in 2012 meant 66.3 GWh of energy was not used. In addition, six system blackouts totaling 20.3 hours reduced total demand. The IPPs had high generation costs. Between 1998 and 2004, which is Part 2, there was an increase in availability due to increased investment in the power sector. The gas pipeline was extended to fuel the 45 MW plant at Tegeta, in Dar es Salaam. Availability of power is decreasing over time in Tanzania due to the over-reliance on hydropower energy, a source that cannot be counted on in dry seasons. Tanzania also has a poor quality of supply and high electricity losses of 21–23% (Tanzania Power Sector, 2012) (Figure 5.5).

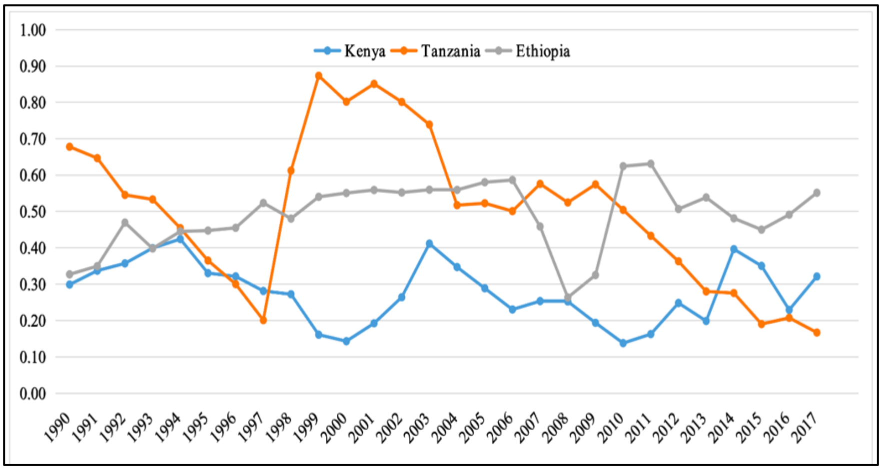

Figure 5.5. Comparative Analysis of Energy availability

In closing, **Kenya** has a low but fairly stable trend of energy availability compared to Ethiopia and Tanzania. Irregular parts of the trend are a result of the severe droughts of 1998, 2000 and 2010–2011. The droughts affected the hydropower generation, which lowered the energy accessible for consumption. The droughts also slowed down the economy, which lowered the investment in the sector due to the slow economic recovery. With programs like universal access to electricity and rural electrification through renewable energy, the country has maintained a fairly steady electricity penetration.

Ethiopia has a medium but increasing energy availability trend over time, with the lowest availability happening between 2006–2008. This was caused by the drought that affected hydropower generation. The medium increase is generally as a result of government projects to expand the generation and explore more renewable energy sources.

Tanzania shows a decreasing trend over the years, although it has, on average, the highest energy availability of 0.5014 compared to 0.2788 and 0.4895 in Kenya and Ethiopia, respectively. The peak was between 1997 to 1999 due to increased investment in the power sector and the gas pipeline for power production. The general decreasing trend is because of the slow economic growth, industrial expansion, and rural electrification, and the population continues to grow. The energy availability ranking index for investigated countries is depicted in Figure 5.6.

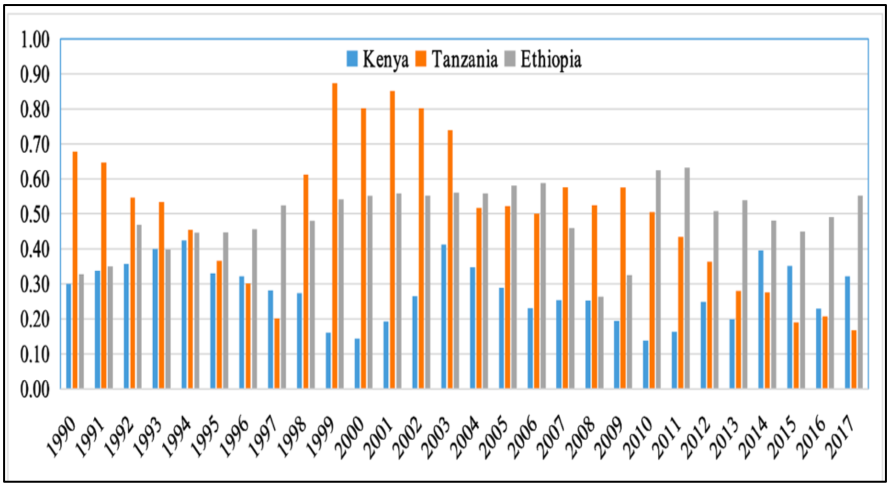

Figure 5.6. Energy availability ranking index

Figure 5.6 shows that Tanzania has slightly higher energy availability, followed by Ethiopia and then by Kenya. This is because Tanzania has higher values for security of supply, diversification rate and self-sufficiency in terms of domestic supply. Table 5.1 illustrates the availability ranking. The ranking was derived from the average of the normalized availability values per country over the period of the study.

Table 5.1. Ranking of energy availability

	Kenya	Tanzania	Ethiopia
Energy Availability	0.2788	0.5014	0.4895
Rank	**3**	**1**	**2**

The related sub-indicators to this availability dimension is presented as follows;

- **Supply security:**

Kenya has been fairly stable over the years because the total primary electricity supply and the utilization rate by the population has not varied much in the study period. Security of supply decreased between 1990 and 1991 because energy consumption grew faster than production. The increasing trend from 2005 towards 2017 is because of an increase in the total primary energy supply, which was orchestrated by the increase in rural electrification and universal access to electricity programs by the government.

In Tanzania, this indicator is generally decreasing, although not exponentially. The decrease between 1990– 1994, from 0.6148 to 0.1025, resulted from the economic crisis. Real per capita GDP in 1992 fell consistently from a peak of TZS 57243 in 1976 to TZS 47743 in 1986, a drop of over 16%. There was a slow recovery after 1986 to the 1990 economic crisis, with a decline of almost 8% between 1991 and 1994, followed by a faster recovery from 1997 onwards (Potts, 2005).

Ethiopia has an increasing trend. This shows that the total primary electricity supply per capita has increased due to electricity supply increasing faster than consumption. This increase is the result of massive investment over the years toward expanding hydropower and renewable energy in Ethiopia (Khan & Singh, 2017; van der Zwaan, Boccalon, & Dalla Longa, 2018) (Figure 5.7).

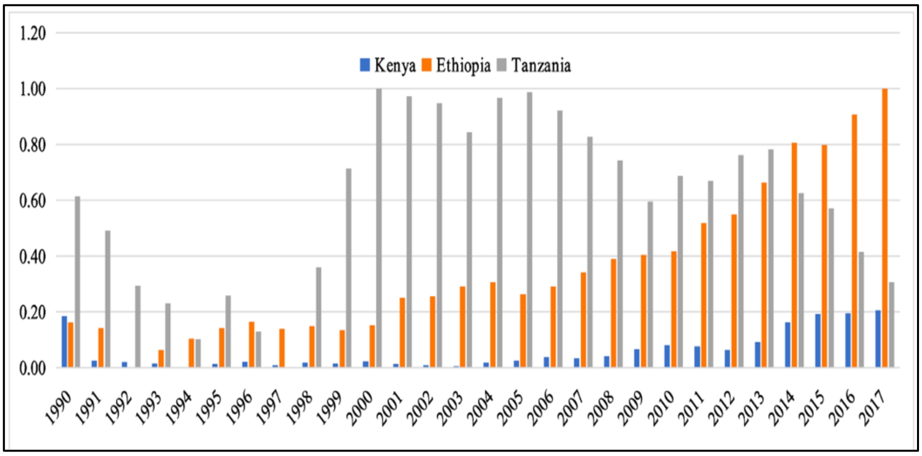

Figure 5.7. Energy supply security ranking

Tanzania has the highest supply security, followed by Ethiopia and lastly Kenya. This means Tanzania sufficient energy supply from domestic resources compared to Kenya and Ethiopia, as illustrated in Table 5.2. The ranking was derived from the average of the normalized supply security values per country over the period of the study.

Table 5.2. Ranking of supply security

	Kenya	**Ethiopia**	**Tanzania**
Supply Security	0.0598	0.3505	0.6010
Rank	**3**	**2**	**1**

- ## Diversification in Electricity

Kenya shows a decreasing trend towards the end of the study period. Kenya's energy mix is dominated by geothermal, hydropower, and thermal power. The country has increasingly invested in hydro and geothermal power generation, expansion, and exploration, with IPPs like the Kenya Tea Development Agency (KTDA) investing in small hydropower plants (Simons & Hunink, 2018; Malala & Adachi, 2020). This investment lowers the diversification rate in Kenya. The country also has no oil reserves or active commercial-scale exploration of oil reserves.

Tanzania: with the recovery of the economy, the country started to diversify its investment in energy sources. The decline at the beginning of the study period resulted from droughts that affected hydro generation and supply. The decline towards the end of the study resulted from Tanzania's decreasing diversification due to major funding of large generation projects like natural gas and hydropower (Ahlborg & Hammar, 2014).

Ethiopia has been on an increasing trend between 1990 to 2006 and 2009 to 2010 but sharply decreased in 2008–2009. The decrease was due to the severe drought experienced in 2008 that derailed diversification strategies like rural electrification programs. The economy picked up but gradually dropped toward the end of the period due to the same reasons (Figure 5.8).

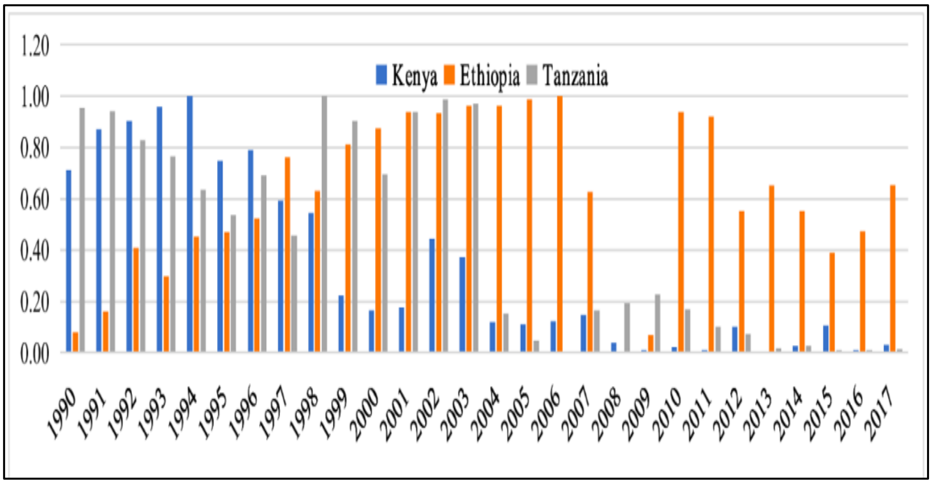

Figure 5.8. Diversification in electricity ranking

Ethiopia has a more energy diverse system, followed by Tanzania and lastly Kenya. This diversity is illustrated in Table 5.3. The ranking was derived from the average of the normalized diversification values per country over the period of the study.

Table 5.3. Ranking diversification in electricity ranking

	Kenya	Ethiopia	Tanzania
Diversification	0.3338	0.6106	0.4466
Rank	**3**	**1**	**2**

- ## Self-sufficiency

Kenya has an increasing trend in self-sufficiency. This shows that the domestic primary energy supply has grown faster than consumption over the period of the study. This increase can be attributed to the growth in generation through the rural electrification and universal access programs. The periods of decrease resulted from the drought that lowered the domestic generation, but the self-sufficiency score bounces back when the economy recovers.

Tanzania shows a decreasing trend because of increased consumption due to population growth and a rise in the economy, but the total primary energy supply has not been increasing. Domestic energy supply is growing faster than energy consumption due to the growth of the economy and more investment in domestic energy generation (Teske, Morris, & Nagrath, 2017).

Ethiopia also has a decreasing trend because domestic energy consumption has grown faster than energy supply due to the low growth of the economy and investment in domestic energy generation (Figure 5.9).

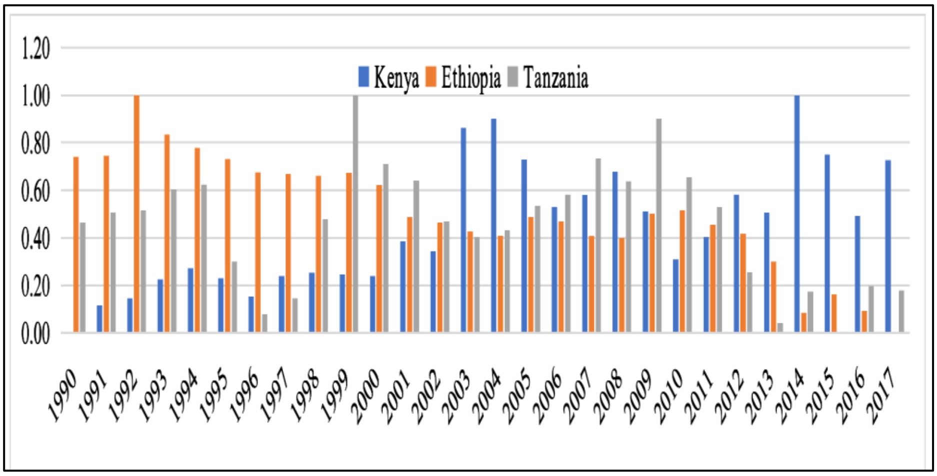

Figure 5.9. Energy self-sufficiency ranking

Ethiopia has the highest self-sufficiency, followed by Tanzania and lastly by Kenya. Ethiopia has energy adequacy due to a sufficient total primary energy supply due to increased investment in power generation, especially hydro. This is shown in Table 5.4. The ranking was derived from the average of the normalized self-sufficiency values per country over the period of the study.

Table 5.4. Ranking energy self-sufficiency

	Kenya	Ethiopia	Tanzania
Self Sufficiency	0.4429	0.5074	0.4567
Rank	3	1	2

5.2.2. *Energy Accessibility*

Kenya

The accessibility dimension has increased over time from 1990 to 2017. This means that there is an increase in both the electric consumption per capita and the electrification ratio. There was a relative decrease in 2000 because of that year's drought. Kenya substantially relies on hydropower. This positive trend can be attributed to the exploitation of renewable resources that the country has been pursuing over the years. Government rural electrification programs aim to provide electricity service connections to 40% of the rural population by 2020 (Jodensvi & Torstensson, 2020). The Last Mile Connectivity Project (LMCP), which was established in 2014 with the aim of attaining universal electricity access by 2020, also has contributed to the upward trend in accessibility (Murphy & Sharma, 2014).

Ethiopia

Ethiopia has an increasing trend in energy accessibility due to the continued exploitation of renewable energy by the government over the period. The massive investment in hydropower plants like the Tekeze, Gilgel Gibe II, and Tana Belese plants has contributed to increasing

Ethiopia‘s hydropower generating capacity. In 2004/05, total hydropower generation was 714 MW, but by the end of 2008, the hydropower generation capacity increased to 3,270 MW, amounting to a 62% increase (Commission, 2016). The increase in hydropower was accompanied by an increase in transmission and distribution networks (Tucho, Weesie, & Nonhebel, 2014). The intermittent reductions in the accessibility were generally due to severe droughts that led to a reduction in hydropower generation (Gebremeskel, Bekele, & Ahlgren, 2019).

Tanzania

The accessibility dimension in Tanzania continued to increase from 1990 to 2017 due to the increasing exploitation of renewable energy and an energy policy that strongly focuses on renewable energy technologies. This policy has also led to an increase in the percentage of the population that has access to electricity. The intermittent decreases in 1994 and 2003 are due to drought that caused a reduction in hydropower generation. There was a large increase between 1997 to 1999 when Tanzania increased its hydropower input to the grid from 1449 to 2162 MW. The rural electrification program also boosted the accessibility dimension (Teske et al., 2017) (Figure 5.10).

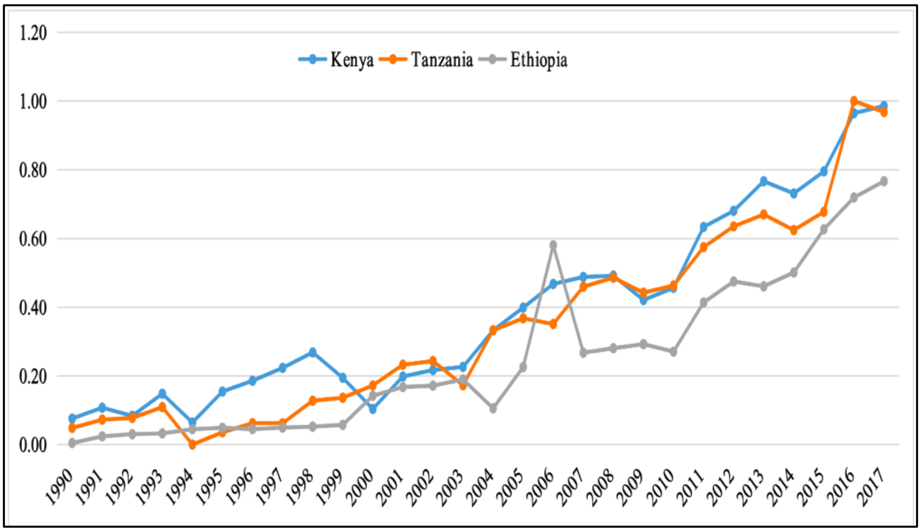

Figure 5.10. Comparative analysis of energy accessibility

Briefly, the three countries have an increasing trend in accessibility over the study; however, there is a sharp increase above the trend in 2006 for Ethiopia. This increase resulted from the extension of the national grid to supply electricity to 335 rural towns and villages, which improved the access rate from 17% to 20%. This access supported social-economic development in rural areas (Aragaw, 2012). The energy accessibility ranking index for investigated countries is depicted in Figure 5.11.

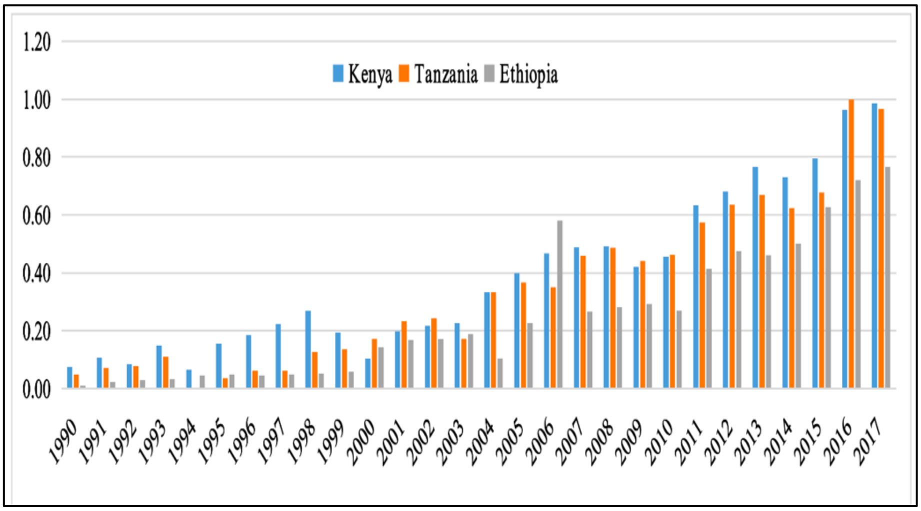

Figure 5.11. Energy accessibility ranking index

Figure 5.8 shows that Kenya has the highest accessibility, followed by Tanzania and then Ethiopia. This ranking is attributed to the high implementation level of universal electricity access and rural electrification programs initiated by the government. Table 5.5 illustrates the accessibility index ranking. The ranking was derived from the average of the normalized energy accessibility values per country over the period of the study.

Table 5.5. Ranking of energy accessibility

	Kenya	**Tanzania**	**Ethiopia**
Energy Accessibility	0.3878	0.3428	0.2515
Rank	**1**	**2**	**3**

- ## Access to Electricity

Kenya: was in an upward trend throughout the study period. However, there was a sharp reduction in electricity access in 2010 and 2014. This can be attributed to the financial crisis of 2009: the effects extended to 2010, thereby reducing purchasing power (Gicheru, 2011).

Tanzania has been on the upward trend with a decrease in 2008–2010. This decrease can be attributed to the effect of recurring drought in 2009/2010, which reduced hydropower generation due to low water in the reservoir. In turn, this led to a decrease in the amount of power accessible in the grid (Falchetta, Gernaat, Hunt, & Sterl, 2019; Loisulie, 2010).

Ethiopia has been on a fairly slow increase with an exponential increase from 2004 to 2006. This is as a result of grid extension for rural electrification, which improved the rate of rural access by 20% in 2006% from 17% in 2004 (Aragaw, 2012) (Figure 5.12).

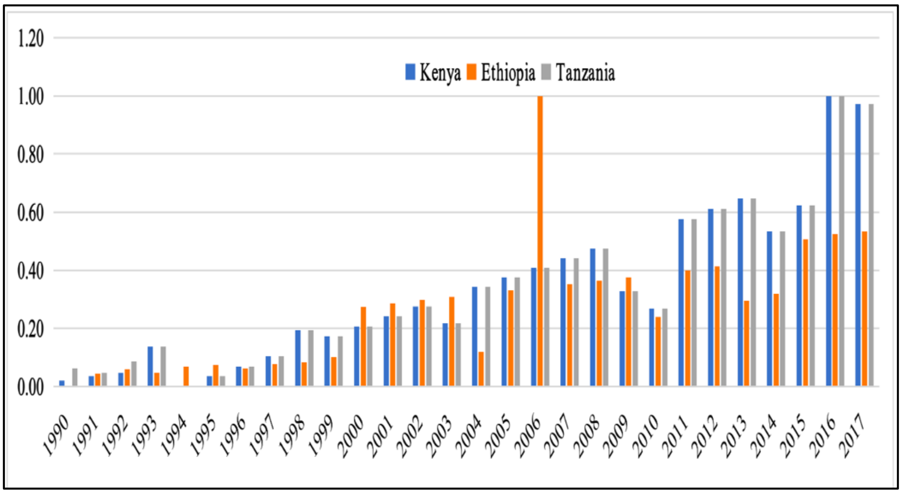

Figure 5.12. Access to electricity (% of population) ranking

Tanzania has more people with access to electricity, followed by Kenya and last Ethiopia. This is due to massive government-run rural electrification programs in Tanzania and Kenya. Table 5.6 illustrates the ranking of access to electricity as a percentage of the population. The ranking was derived from the average of the normalized access to electricity as a percentage of population values per country over the period of the study.

Table 5.6. Ranking access to electricity (% of population)

	Kenya	**Ethiopia**	**Tanzania**
Access to electricity (% of population)	0.3338	0.2698	0.3373
Rank	**2**	**3**	**1**

- ## Electricity Consumption per Person

Kenya has been on the upward trend with a sharp decrease in 1998–2000 due to Kenya's worst drought in 60 years. According to the World Bank, there was a long-term economic decline that pushed 48% of the rural population to absolute poverty by 2000, thereby reducing the purchasing power (Wambugu, 2010).

Tanzania has been increasing as a result of intense rural electrification programs the government has been implementing and also the rise in the economy, which has increased the purchasing power of the people (Khan & Singh, 2017; Mondal, Bryan, Ringler, Mekonnen, & Rosegrant, 2018).

Ethiopia has been on the rise throughout the study period. This increase can be attributed to the rising economy of the country, which has increased the purchasing power of the people (Figure 5.13).

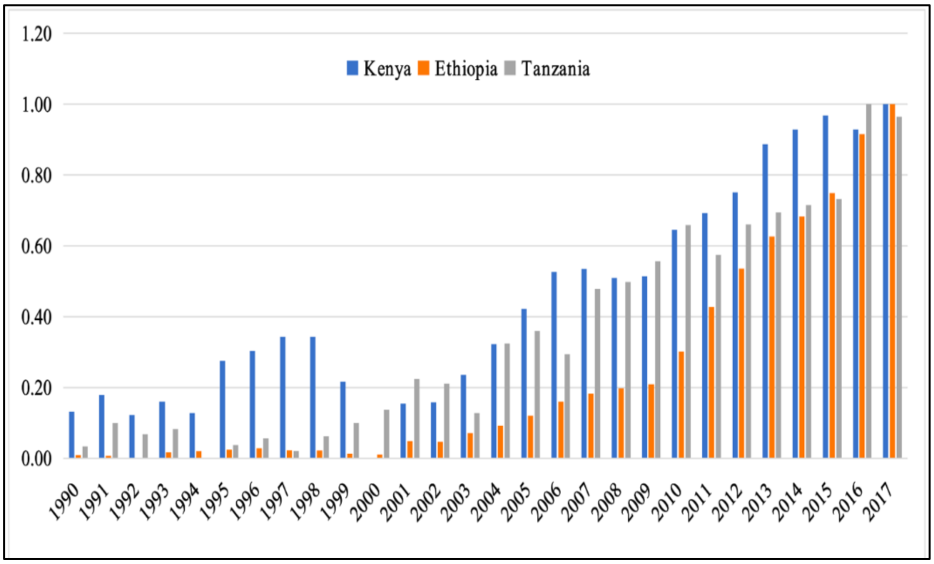

Figure 5.13. Electricity consumption per person ranking

More people have access to commercial energy in Kenya than in Tanzania and Ethiopia. This access promotes an equal society where generation is available to match the population's needs, as is illustrated in Table 5.7. The ranking was derived from the average of the normalized electricity consumption per person values per country over the period of the study.

Table 5.7. Ranking electricity consumption per person

	Kenya	Ethiopia	Tanzania
Electricity consumption per person	**0.4417**	**0.2331**	**0.3484**
Rank	1	3	2

5.2.3. *Energy Acceptability*

Kenya

Kenya is moderately increasing over the study period, but a sharp increase can be observed between 1999–2000. This increase, and the increase in 2009, have been attributed to poor dam flows due to the severe droughts that affected the hydropower generation. As a result, expensive thermal power plants were required to provide the base load leading to an increase in CO_2 emission per unit of energy consumption. The reduction in the acceptability experienced between 2001–2003 resulted from the increased installation of renewable energy and the shutdown of thermal power plants as hydropower was sufficient during the period. Geothermal generation improved to 19.9% (1,453 MW) from 12.5% (205 MW), respectively (Ellis, Lemma, Mutimba, & Wanyoike, 2013).

Ethiopia

There is a fluctuating increase in the energy acceptability but a sharp drop in 1991–1992 because of the fluctuating economic growth in the period and reliance on thermal plants as an alternative to hydropower. Acceptability rose sharply in 2000–2003 when the economy experienced a boom, which had a significant effect on economic growth and, by extension, on the standard of living. This boom also affected CO_2 emission levels. Economic growth experienced another fluctuation between 2004–2011, accompanied by changes in CO_2 emission (Taka, Huong, Shah, & Park, 2020).

Tanzania

Tanzania is on the upward trend but fluctuating for the study period. This can be attributed to the fluctuation in the economic growth and the drought, which causes a decline in hydropower and an increase in the use of thermal power to generate electricity (Albiman, Suleiman, & Baka, 2015) (Figure 5.14).

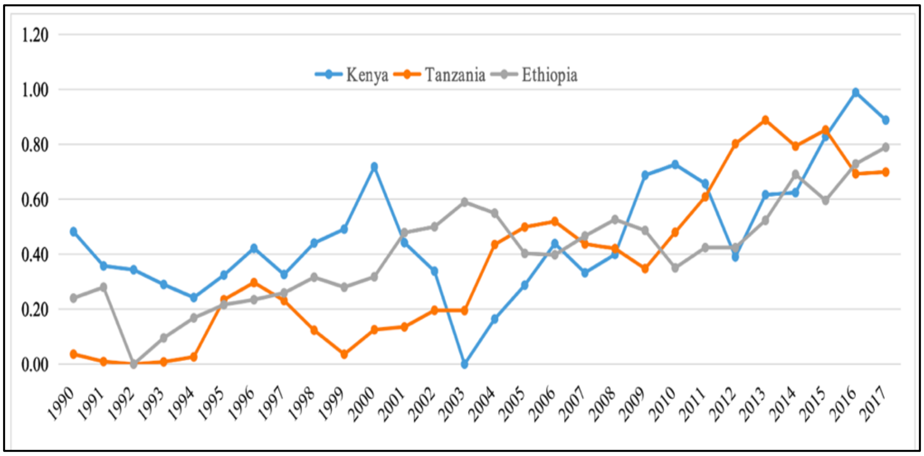

Figure 5.14. Comparative analysis of energy acceptability

In conclusion, all three countries have a positive trend. This means that the countries have emitted more CO_2 to achieve a high GDP over the years. The GDP has been on the rise in the three countries, making energy consumption rise, thereby increasing both the CO_2 intensity and energy-related emissions per GDP. The energy acceptability ranking index for investigated countries is depicted in Figure 5.15.

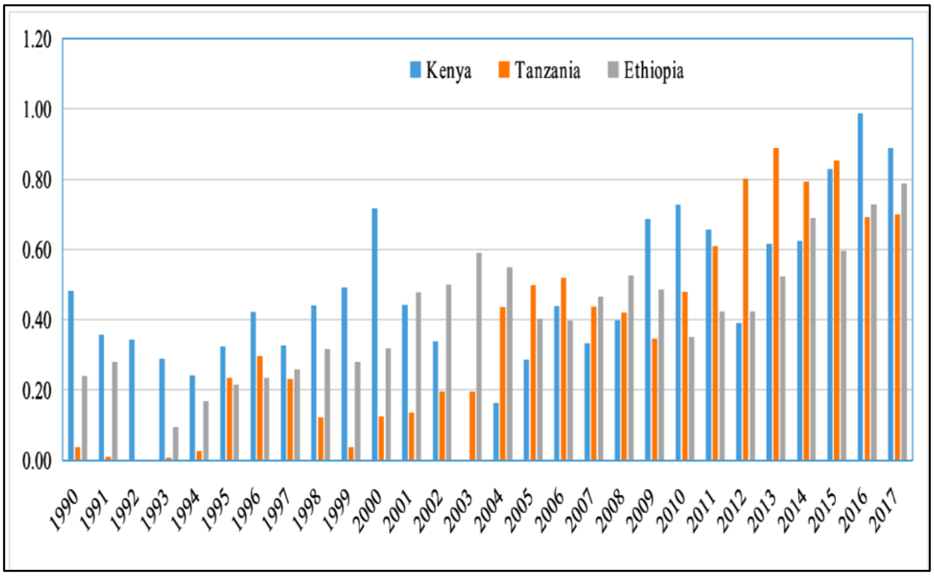

Figure 5.15. Energy acceptability ranking index

Tanzania has the highest energy acceptability, followed by Ethiopia and then by Kenya. This is attributed to the high implementation level of renewable energy technologies in Tanzania, as shown in their energy mix in Figure 6.1. Table 5.8 below shows the ranking of this dimension. The ranking was derived from the average of the normalized energy acceptability values per country over the period of the study.

Table 5.8. Ranking of energy acceptability

	Kenya	**Tanzania**	**Ethiopia**
Energy Acceptability	0.4731	0.3618	0.4047
Rank	**3**	**1**	**2**

- **Emission Intensity**

Kenya: The emission intensity values attributed to energy generation, the economy (production), and the population have a similar trend; the trend fluctuates and has highs and lows. An exponential increase in the period between 1998– 2000 was attributed to poor dam flow due to the drought. As a result, the government resorted to thermal power plants for base load power, which, in turn, led to an increase in CO_2 emission per energy consumption. A reduction of emissions between 2001– 2003 was attributed to recovery from the drought and economic meltdown. The government shut down the thermal power plants as base load to concentrate on hydropower and other renewable sources of energy such as geothermal, wind, and solar (Owiro, Poquillon, Njonjo, & Oduor, 2015).

Tanzania: The emission intensity attributed to energy generation, the economy (production), and the population has a similar trend. The trend is fluctuating with high and lows. This fluctuation can be attributed to fluctuating economic growth. During the dry seasons, the country operates more diesel power plants to offset the hydropower deficit. The population has also been increasing, causing a ripple effect on the emissions (Albiman et al., 2015).

Ethiopia: The emission intensity attributed to energy generation, the economy (production), and the population has a similar increasing trend for the period of the study, this is because of the increased use of energy due to increased use of electricity that can be attributed to an increase in population over the period, and this has increased CO_2 over time. Emission intensity attributed to economic production has fluctuated over the study period. The sharp decline in CO_2 between 1991 and 1992 was due to the fall in the GDP, which resulted in a decrease in energy consumption and hence lower emissions. However, emissions and energy consumption rose with the rise in the economy but again normalized towards the end of the study period (Engdayahu, 2007; Taka et al., 2020) (Figures 5.16 to 5.18).

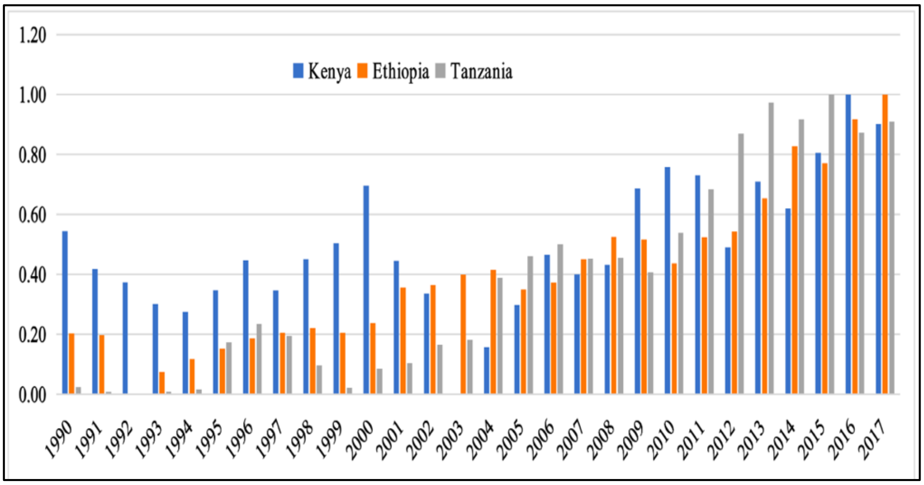

Figure 5.16. Emission intensity (Energy wise) CO2/TPES ranking

Tanzania has the lowest energy intensity, followed by Ethiopia and then Kenya. This ranking reflects Tanzania's use of low carbon energies and better energy consumption efficiency. Tanzania's ranking is due to the application of renewable energy technology in the power system. The CO_2 emissions/TPES ratio reflects the energy mix among oil fuels and natural gas and energy use efficiency. Table 5.9 illustrates the ranking. The ranking was derived from the average of the normalized emission intensity due to energy generation values per country over the period of the study.

Table 5.9. Ranking emission intensity (Energy wise) CO2/TPES

	Kenya	**Ethiopia**	**Tanzania**
Emission Intensity (Energy wise) CO2/TPES	**0.4979**	**0.4009**	**0.3833**
Rank	3	2	1

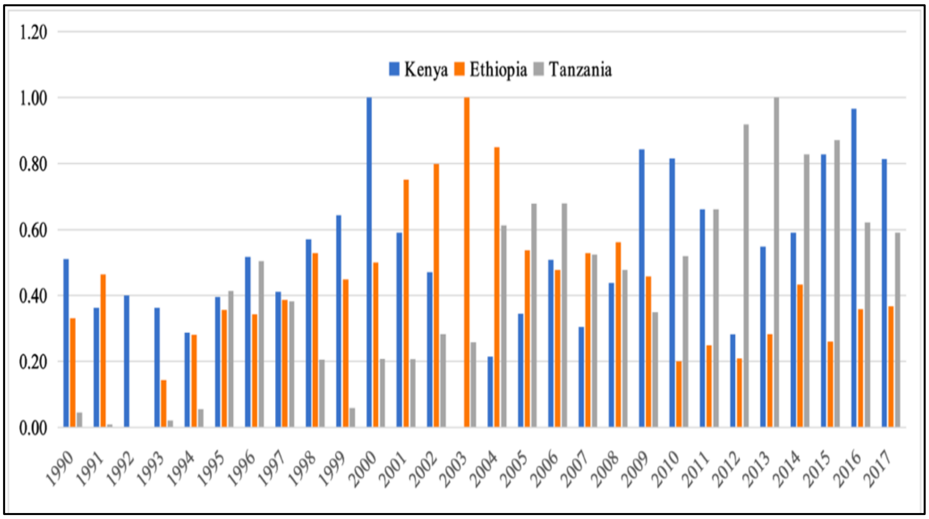

Figure 5.17. Emission intensity (Economic wise) CO2/GDP

Tanzania has lower emission intensity due to the economy, followed by Ethiopia and then by Kenya. The lower the emission, the better the security. This ratio measures CO_2 in terms of its relationship to economic growth. Table 5.10 below illustrates the ranking of the sub-index. The ranking was derived from the average of the normalized emission intensity due to the economy values per country over the period of the study.

Table 5.10. Ranking emission intensity (Economic wise) CO2/GDP

	Kenya	**Ethiopia**	**Tanzania**
Emission Intensity (Economic wise) CO2/GDP	**0.5244**	**0.4323**	**0.4280**
Rank	3	2	1

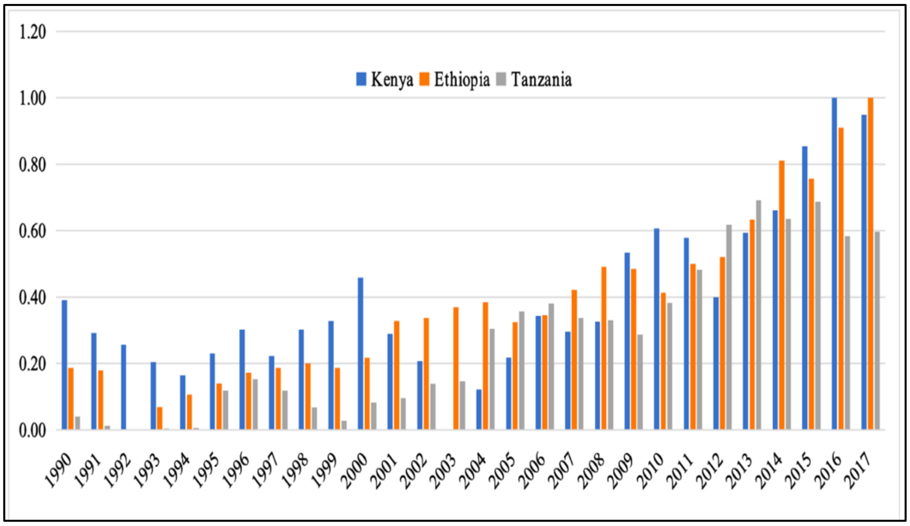

Figure 5.18. Emission intensity (Population wise) CO2/Pop

Tanzania has the lowest CO_2 emissions per capita, making it the highest in terms of security, followed by Ethiopia and then Kenya. This level of CO_2 emissions per capita is the measure of the amount of fossil fuel used per person and more closely reflects the extent of economic growth and its relationship to CO_2. Table 5.11 illustrates the ranking of emission intensity. The ranking was derived from the average of the normalized emission intensity due to the population values per country over the period of the study.

Table 5.11. Ranking emission intensity (Population wise) CO2/Pop

	Kenya	**Ethiopia**	**Tanzania**
Emission Intensity (Population wise) CO2/POP	0.3970	0.3809	0.2739
Rank	**3**	**2**	**1**

5.2.4. *Energy Efficiency*

Kenya

Kenya is in a decreasing trend over the study period. There is, however, an upward trend between 1999– 2002, showing that energy efficiency was going down. This decrease resulted from the increase in demand with lower GDP, as the country was recovering from a period of economic crisis. The efficiency then increased from 2002 onwards as the country recovered from the economic crisis (Semboja, 1994).

Ethiopia

Ethiopia has a fluctuating but positive energy efficiency trend, showing that it has become less efficient over the study period. The value, however, decreases between 2003–2009, showing an increase in energy efficiency attributed to the massive investment in renewable energy intensity (TPES/GDP), and, therefore, an improvement in energy efficiency. The increase between 2009– 2012 is an indication of worsening energy efficiency. This can be attributed to the increase in energy intensity due to the rise in the economy (Mondal et al., 2018).

Tanzania

Tanzania is showing a downward trend, showing an increase in energy efficiency over time. This can be attributed to the GDP growth rate being higher than the growth in the energy consumption rate, and the reversals that are seen are attributed to energy demands increasing more than the GDP growth in Tanzania. Tanzania has also been increasing its investment in renewable and smart energy technologies to reduce transmission and distribution losses (Mohamed & Kahn, 2008) (Figure 5.19).

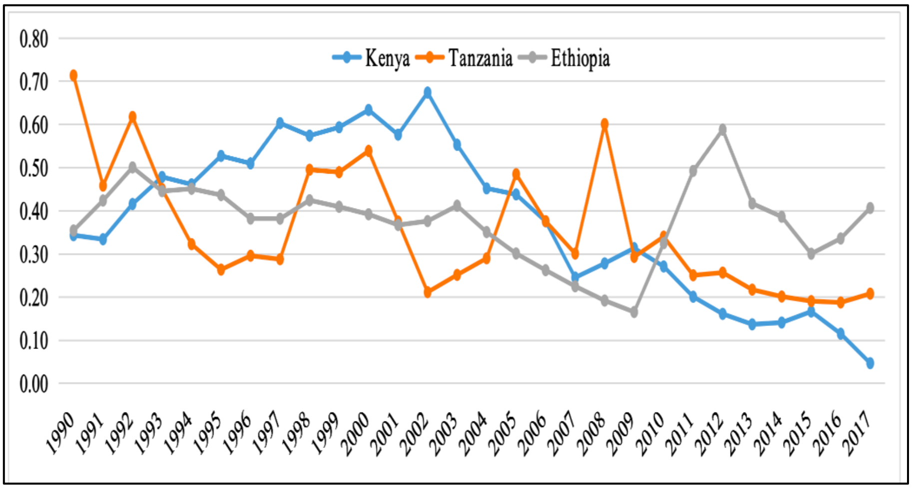

Figure 5.19. Comparative analysis of energy efficiency

In closing, **Kenya** and **Tanzania** have a downward trend. This shows positive energy efficiency in the two countries that can be attributed to the GDP growth rate being higher than the growth in the energy consumption rate over the period. **Ethiopia** has a slightly increasing trend in the long run, which signifies decreasing energy efficiency in the long run. This trend can be attributed to the increase in energy intensity due to the rise of the economy and the slow penetration of efficient technologies in the energy sector, contributing to high energy distribution losses. The energy efficiency ranking index for investigated countries is depicted in Figure 5.20.

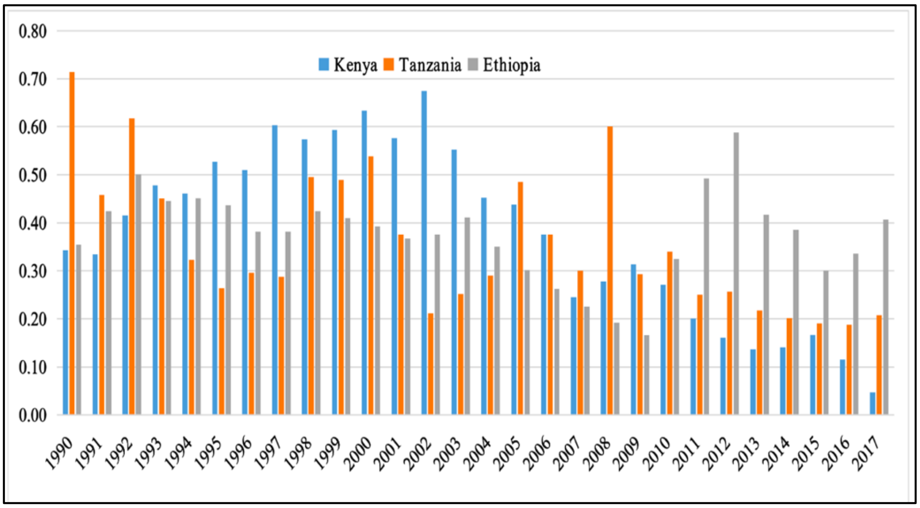

Figure 5.20. Energy efficiency ranking index

Tanzania has slightly higher energy efficiency, followed by Ethiopia and then Kenya. This ranking is attributed to decreasing levels of energy intensity due to the increasing implementation of renewable energy technologies in the country. These new, efficient technologies also reduce distribution and transmission losses. Table 5.12 illustrates the ranking of energy efficiency for the selected countries. The ranking was derived from the average of the normalized energy efficiency values per country over the period of the study.

Table 5.12. Ranking of energy efficiency

	Kenya	Ethiopia	Tanzania
Energy Efficiency	0.3794	0.3561	0.3752
Rank	**3**	**1**	**2**

- **Electric Power Transmission and Distribution Losses (% of output)**

Kenya has a fluctuating but increasing trend between1992–2002, which means more electricity was lost through transmission and distribution. These losses can be attributed to inefficient technologies like the thermal power plants that were used as base load power during the period of low water in the reservoir due to the severe drought. The trend, however, started decreasing from 2002 to the end of the study period, indicating a reduction in transmission and distribution losses. This decrease is attributed to the implementation of renewable energy and improved technology programs through the rural electrification and universal access to energy programs (Behrens et al., 2012; Mohamed & Kahn, 2008).

Tanzania has fluctuated throughout the study period. The fluctuation can be attributed to the fluctuation in the economic growth in the country, resulting in shifting access to electricity or connection rate, which results in the shift in consumption rate.

Ethiopia is consistently low from 1990–2009, signifying less power and distribution losses. At the beginning of 2009–2012, the amount increases as a result of an increase in energy intensity (Figure 5.21).

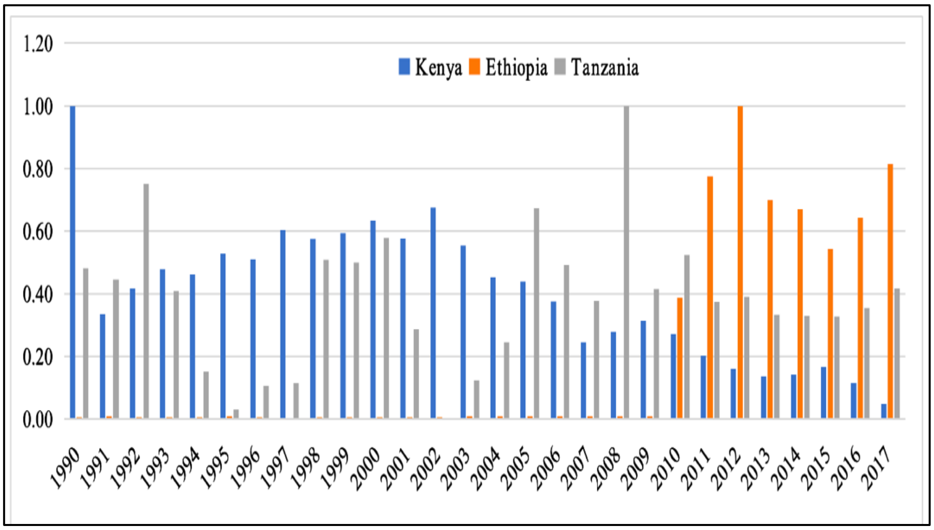

Figure 5.21. Electric power transmission and distribution losses (% of output)

Ethiopia has the lowest power electric power transmission and distribution losses as a percentage of output, followed by Tanzania and then by Kenya. This can be seen as a direct measurement of the level of stability of the power supply. Table 5.13 illustrates the electric power transmission and distribution losses as a percentage of output ranking. The ranking was derived from the average of the normalized electric power transmission and distribution losses as a percentage of output values per country over the period of the study.

Table 5.13. Ranking electric power transmission and distribution losses (% of output)

	Kenya	Ethiopia	Tanzania
Electric power transmission and distribution losses (% of output)	0.4028	0.1986	0.3831
Rank	**3**	**1**	**2**

- **Energy Intensity**

Kenya has a fairly stable trend in the long run, but an increasing trend is observed between 1995–2002. This increase can be attributed to the rate of energy consumption increasing faster than the GDP growth. Therefore, Kenya's energy consumption tends to be more wasteful during the period. The trend, however, goes down and normalizes because of a rise in the GDP over time and an improvement of energy technologies (Kasae, 2014; Sarkodie & Adom, 2018).

Tanzania: The trend is decreasing over time, showing an increase in energy intensity in the long run due to a rise in the GDP over time.

Ethiopia: The trend is decreasing over time, showing an increase in energy intensity in the long run. This can be attributed to the rise in GDP over time (Figure 5.22).

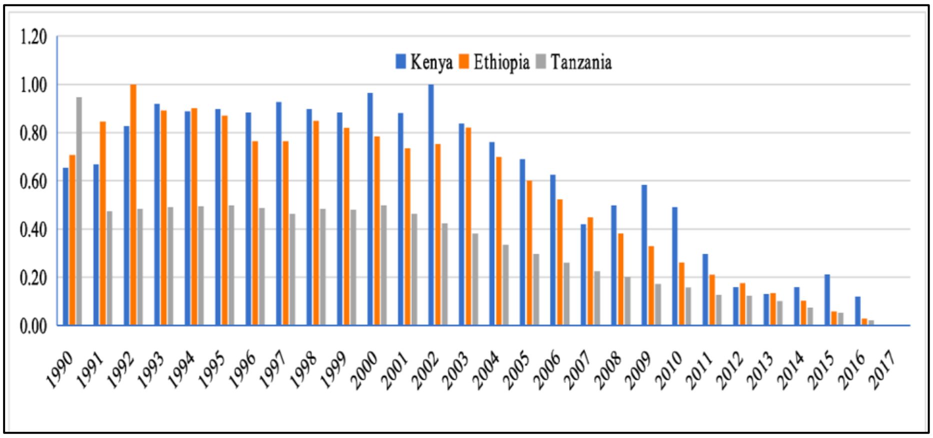

Figure 5.22. Energy intensity

Tanzania has a low energy intensity, followed by Ethiopia and Kenya. This low energy intensity indicates lower prices or a lower cost of converting energy into GDP in Tanzania compared to Ethiopia and Kenya. Energy intensity measures the energy inefficiency of an economy because using less energy to produce a product reduces the intensity. Table 5.14 illustrates the energy intensity ranking. The ranking was derived from the average of the normalized energy intensity per country over the period of the study.

Table 5.14. Energy Intensity

	Kenya	Ethiopia	Tanzania
Energy Intensity (TPEC/GDP)	**0.6168**	**0.5519**	**0.3292**
Rank	3	2	1

5.3. Energy Security Ranking

The energy security ranking of selected East African countries is provided in this section.

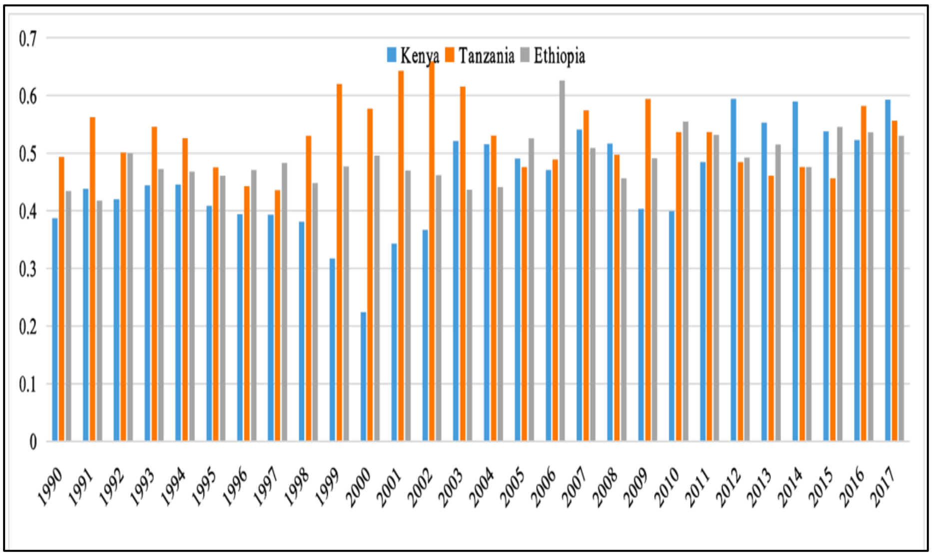

Figure 5.13. Energy security index ranking

The study reveals that Tanzania has the highest energy security, followed by Ethiopia and then by Kenya. This is because the **Energy Security Index ranking** has the highest energy efficiency, which means it has low energy intensity, which increases the country's energy security. In addition, Tanzania has lower power distribution losses and more domestic total primary supply than Kenya and Ethiopia. The country also has the highest energy availability compared to the two countries in the study. The overall energy security ranking index rankings are shown in Table 5.15. The ranking was derived from the average of the normalized overall energy security per country over the period of the study.

Table 5.15. Energy security index ranking

	Kenya	Tanzania	Ethiopia
ESI	0.3796	0.3905	0.3802
Rank	**3**	**1**	**2**

5.4. Discussion

Kenya's energy mix is dominated by geothermal, hydro, and oil fuel at 47%, 31%, and 20%, respectively. Tanzania's energy mix is primarily natural gas at 47% and hydro at 32%. The majority of Ethiopia's energy mix is hydro, at 95%. These relative source mixes make a substantial contribution to energy security, apart from economic and population growth. These energy sources are illustrated in Tables 5.16, 5.17, and 5.18.

Table 5.16. Fuel mix in Kenya (2017)

	Installed GWh	Installed Capacity (%)
Oil	2094	20.2 %
Biofuel	126	1.2 %
Hydro	3206	31.0 %
Geothermal	4810	46.5 %
Solar PV	71	0.7 %
Wind	48	0.5 %
Total	**10355**	**100.0 %**

Source: International Energy Agency

Table 5.17. Fuel mix in Tanzania (2017)

	Installed GWh	Installed Capacity (%)
Coal		
Oil	1361	18.8
Natural gas	3427	47.3
Biofuel	72	1.0
Hydro	2350	32.4
Solar	39	0.5
Total	**7250**	**100.0**

Source: International Energy Agency

Table 5.18. Fuel mix in Ethiopia (2017)

	Installed GWh	Installed Capacity (%)
Oil	4	0.0 %
Hydro	12681	95.8 %
Geothermal		
Solar	22	0.2 %
Wind	533	4.0 %
Total	**13240**	**100.0 %**

Source: International Energy Agency

The countries under study have two seasons: dry and rainy. This seasonal variation has contributed to the availability and the security of energy as a whole. During the dry seasons, most countries revert to using thermal power, which increases the emission intensity. During the dry seasons, purchasing power goes down, thereby affecting economic growth.

Chapter 6
Conclusions and Policy Implications

6.1. Conclusion

Since the Energy Act in 2006, energy security has been a priority for the Kenyan government. The government recognizes that, as a developing country, how it manages its resources and implements policies to balance energy demand and supply is essential. The government plays a big role in regulating and managing the country's energy security. For the Kenyan government to achieve its Vision 2030 and the big four agenda, ensuring energy independence and security must be its first priority, emphasizing domestic energy resources.

Kenya's energy policy primarily focuses on availability. The government has tried to diversify its energy resources, self-sufficiency and increase its supply security by introducing the rural electrification and universal access to power programs and exploiting alternative and renewable energy resources by the strategy of low electricity tariffs. These efforts have improved energy security by far, but more strategies need to be put in place for the country to be energy secure.

This study evaluated energy security performance through the energy security index method between 1990 and 2017. The selection of the dimensions and sub-indicators was based on the existing literature reviews and localized to suit our study. An energy security model was built from the existing literature to qualitatively analyze the energy security in Kenya. The dimension was selected based on the existing energy laws in the country. The indicator was derived from the dimensions with references from other studies.

The study has evaluated ten indicators grouped into four dimensions of energy security: availability, accessibility, acceptability, and energy efficiency. The dimension and indicator scores are then harmonized through the methodology's normalization process.

The **availability** dimension of energy security in Kenya has considered three indicators. The highest score, in 1994, was attributed to economic recovery and the lifting of the donor aid embargo to the power sector in the late 1990s and the significant power reforms that liberalized power generation thereby, allowing independent power producers to participate in power generation.

The **accessibility** dimension in Kenya is on the increasing trend throughout the study period, and this shows the improving electrification ratio and electricity consumption per capita in Kenya. This is as a result of the electrification programs the government is running, i.e., rural electrification and the universal access programs.

The third dimension is **acceptability**. The study considered three indicators to develop emission intensity. The first indicator is emission intensity in terms of energy (emissions released per consumption of unit of energy); this indicator has worsened during the study period. Emission intensity in terms of economic growth (with the growth of the economy, energy demand becomes higher, thereby leading to an increase in emissions) shows a negative trend. In other words, Kenya emits more CO_2 to realize a higher GDP over the study period.

The **energy efficiency** dimension measures the total primary energy consumption over GDP and the electric power transmission and distribution losses as a percentage of energy out. This indicator performed poorly at the beginning of the study but improved towards the end of the study. This improvement results from a rise in the GDP and the implementation of efficient energy technologies in the system.

This study shows that with proper policies in place like the electrification programs, use of efficient technologies, and continuous exploitation of renewable energy resources, Kenya can improve its energy security.

6.2. Policy Implications

The results of this study suggest a number of policies that can be recommended to the electricity industry in Kenya to improve the energy security situation and realize Vision 2030. First, Kenya needs to improve its energy availability by improving supply security, fuel diversification, and becoming energy self-sufficient. That is, the country needs sufficient energy supply from domestic resources to achieve energy adequacy.

Although Kenya has policies like universal access to electricity and rural electrification programs, it must strengthen these policies and the relevant institutions mandated with the execution of the policies. The government should also implement a clear road map to improving the share of renewable energies such as wind, solar, and bio-fuel energy. Lastly, the government should increase the exploitation of other alternative forms of energy like nuclear power to improve domestic production.

The study shows Kenya performing well in energy accessibility, attributed to the rural electrification program and the country's ongoing exploitation of renewable energy resources. This effort is, however, not adequate, and the government needs to build more energy infrastructure. Energy acceptability analyzed emission intensity from energy generation, the economy, and the population. Government strategy to reduce emission intensity should not curtail the country's economic growth. We propose that the government should increase investment in new and renewable sources of energy to create employment and spur GDP growth while ensuring a secure energy future.

The cost of power also affects economic activities, especially energy-intensive consumers such as steel, cement, and paper production. Therefore, a special tariff for heavy industries should be put in place to encourage industrial growth, which will, in turn, lead to a rise in GDP. Finally, the government can improve energy resource conservation strategies to improve its energy efficiency and focus on demand-side management activities to reduce transmission and distribution losses.

6.3. Study limitation and future work

This study achieved its objective of evaluating energy security and response to climate change in selected East African countries with a case study of Kenya to guide the policy makers. However, the analysis was confined to the electricity sector, which is a smaller focus than the scope of research that was originally introduced. This model also did not include the affordability dimension in its analysis due to inadequate data on the dimension. Affordability emphasizes providing energy at a low cost that is affordable to the local economy by evaluating the price of electricity to the GDP-per-capita ratio.

The comparative analysis and the study were carried out at the state level. Therefore, it is important to note that this model did not capture some features of energy security. The model provides basic insight on energy security in the electricity sector and relevant policies that should be put in place for the country to be energy secure. Fundamentally, there is room to improve this tool by perfecting consistent methodologies to estimate these indicators and to include the results in this model.

In conclusion, there is room for improvement of this study by addressing the above-mentioned limitations in future studies. It is, however, believed that the methodology used and the recommendations proposed in this study based on the analysis of the energy security dimensions and indicators would indeed help the policymakers in the country attain future energy security.

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요약

(Abstract)

현대화와 인구 증가로 인해 에너지 안보는 항상 전 세계 모든 국가의 관심사가되어 왔으며, 에너지 사용이 급격히 증가하고 사람들의 삶과 국가 경제가 에너지 사용에 의존하게되었다. 케냐는 전력에 대한 보편적 접근의 비전과 국가 경제 청사진인 '비전 2030'을 달성하기 위해 노력함에 따라 증가되는 전력 수요를 충족하기 위해 광범위한 확장의 필요에 직면 해 있다. 따라서 안정적인 전력공급을 위한 투자가 필수적이다. 이 연구는 케냐의 에너지 안보와 기후 변화에의 대응을 분석하고 지금까지 케냐 정부가 채택한 다양한 정책 및 제도적 전략을 다른 동 아프리카 국가와의 비교하는 것을 목적으로 한다. 이 연구는 에너지 안보를 가용성, 경제성, 접근성, 수용 가능성 및 효율성 세부차원에서 분석하기 위해 에너지 보안 지수 (ESI) 모델을 적용하였다. 에너지 보안 지수 모델은 3 단계로 구성되며 각 지표별로 값을 계산하고 전체 보안지수를 종합 하는 방법이다. 이 연구를 기반으로 케냐 전력 산업의 정책 입안자, 의사 결정자 및 이해 관계자가 고려할 다음 정책 권장 사항이 제시되었다. 정부는 기후 변화에 영향을 미치는 예상되는 영향에 대처하기 위해 대체 및 재생 가능 에너지 자원의 점유율을 늘려야한다. 또한 전력의 지배적 원천 중 하나이며 공급의 안보를 강화 수력 발전에 지속적인 투자를 하여야 한다. 또한 특정 기술(자원)에 대한 의존도를 줄이고 에너지 믹스를 다양

화해야한다. 마지막으로 전력소비효율성을 증가시키는 다양한 형태의 소비부문 관리정책이 필요하다.

키워드 : 에너지 안보, 전력산업, 동아프리카 국가

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