UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

EXPLORING IMPLICATION OF RENEWABLE ENERGY TRANSITION ON THE COST OF ELECTRICITY AND GREEN HOUSE GASES EMISSION IN EAST AFRICAN COUNTRIES

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Declaration

I, the undersigned, declare that this Dissertation is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials used for the dissertation work have been fully acknowledged.

Names: Ngetich E. Kiprotich **Signature**

Main Supervisor: Dr. Hakizimana Khan Jean de Dieu **Signature**

Dedication

I dedicate this work to my mother Christine Too, my father Joseph Too and my entire family and friends.

Acknowledgment

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Abstract

The increasing demand of energy coupled with continuous reliance on non-renewable energy resources as least-cost power generation option contributes highly on climate change. The decision making to having access to a cost-effective and environmentally friendly source of energy relies increasingly on an economic and environmental assessment to inform evidence-based policy set-up for renewable energy (RE). The previous studies fail to capture the decrease in RE capital cost due to learning curves; country specific load profile and capacity build out of potential of renewable energy sources. The aim of this research is to explore the implication of RE transition on cost of electricity generation and greenhouse gas emission in East African Countries. The study applied a scenario capacity expansion model (System Planning Test) to investigate implication of changing penetration level of RE from the reference least cost solution in existing national and regional policy documents on the overall costs of building and operating an electricity system and the derived carbon dioxide emission level.

The results showed that the relationship between RE and the electricity system cost is non-linear. Thus implying that small changes in the level of renewable penetration relative to least cost solution result to small changes in the system costs (changing level by ± 10% leads to less than 2% changes in the system costs). Contrary, large deviation leads to large changes in the system costs (± 25% leads to over 15% changes in the system costs).The higher levels of RE lead to 90% reduction of carbon dioxide levels relative to least cost solution but with higher overall system costs. While lower levels of RE leads to higher carbon dioxide emission levels at lower system costs. Thus evaluating the trade-off between emission saving and system cost, shows that cost of avoiding emissions is incremental to RE deployment and declines as RE is curtailed. Based on the findings, initiatives to promote RE growth in order to meet the Sustainable Development Goals have been proposed. The study also proposed the future study to incorporate the aspect of electricity trade and storage implication.

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Abbreviation and Acronyms

RE	-	Renewable Energy
CO_2	-	Carbon dioxide
LCOE	-	Levelized cost of Electricity
GHG	-	Green House Gases
SPLAT	-	System Planning Test
IRENA	-	International Renewable Energy Agency
ACEC	-	Africa Clean Energy Corridor
UN	-	United Nations
IEA	-	International Energy Agency
EAPP	-	East Africa Power Pool
EACREE	-	East African Centre for Renewable Energy and Energy Efficiency
GDP	-	Gross Domestic Product
LEAP	-	Long Range Energy Alternative Planning
TIAM-ECN	-	TIMES Integrated Assessment Model - Energy Research Center
SWITCH	-	Solar and Wind energy Integrated with Transmission and conventional
WEAP	-	Water Evaluation and planning system
VOM	-	Variable Operation and Maintenance
O&M	-	Operation and Maintenance
PIDA	-	Program for Infrastructure Development in Africa Priority Action Plan

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CHAPTER 1: BACKGROUND AND INTRODUCTION

1.1 Background of the study

Globally due to the uncontrolled increase in the level of Greenhouse gases(GHG) emission from the energy sector majorly, there has been a set off worldwide signal priority given to renewable energy transition and partly energy efficiency to lessen the effects of climate change and global warming (WEC, 2019).The emissions have been increasing gradually since 1970 and the most emission is from Energy, residential and Industrial sector meaning it is as a result of consumption of fossil fuel energy sources (Azhar Khan et al., 2014). Renewable energy is a promising source of long-term, affordable, and environmentally friendly energy in both low and high-income nations, and it has recently attracted investment in the search to fulfill rising demand and create a low-carbon economy (Mabea, 2020).The importance of Renewable energy (RE) in an economy has triggered several studies on the prospects and implications of deploying RE. It plays a crucial role in the attainment sustainable development, boosting energy access and poverty reduction while reducing greenhouse gas emissions, which are harmful to the environment (Zwaan et al., 2018).

There is need for Africa to follow this development projection as lack of affordable electricity is a major determinant of poverty in the region - currently over 588 million in sub-Saharan Africa lack access to electricity (Deichmann et al., 2011; Energy & Special, 2018).Energy sector can really contribute towards achieving the Africa Unions Agenda 2063 and attaining Sustainable Development Goals (SDGs) in terms of production, supply and distribution by producing and delivering secure, affordable and environmentally friendly sources (Akinyemi et al., 2019).However, as much as there has been some progress and commitment of scaling up access to Renewable Energy (RE) in East Africa, having drafted policies that promote investment of RE coordinated independently by countries they still consider fossil fuel sources for electricity generation while also heavily relying on hydropower source which can be vulnerable to the climatic conditions (Energy Special, 2018).

However the technological, environmental, economic, and even institutional ramifications of implementing and integrating renewable energy into the energy system are enormous. Particularly the institutional implication result from market rules and regulations of protecting the industry from high prices and promotion of the investment of RE sources through Feed-in-Tariffs (FITs), Incentives and tax holidays (Verzijlbergh et al., 2017).The technical implications has to do with the price volatility and infrastructural pliancy to support the intermittent nature of RE sources (Sovacool et al., 2018).

The growing concern about the environment has prompted research into new ways to use clean and sustainable energy. For example, in Europe, there is a typical framework "20 20 20" climate and energy package (Mabea, 2020). In Africa, the Africa Clean Energy Corridor (ACEC) initiative has been approved to facilitate regional collaboration in the promotion of regional electricity commerce and renewable energy deployment (Saadi et al., 2015). East African countries are abundant in renewable energy (RE) sources, with an average of 320 days of sunlight each year out of 365 days in a year (IEA, 2019a). In addition, the region possesses a geothermal energy potential of between 10 and 15 GW, with the most of it located in Kenya and Ethiopia. (Mabea, 2020).

Over the time, final energy demand in East Africa increased by over 5% annually on average, while GDP increased at a faster rate of over 5.5 percent on average (1993-2017) (IRENA, 2021). On the other hand, per capita power use remained modest at 663 kWh, with just a 113 kWh rise during the time (IRENA, 2021). The region, however, has challenges associated with energy access, economic development, and energy supply security (UNIDO, 2016). Given the region's strong renewable energy potential, renewables provide an excellent chance to boost power generation capacity in the electricity industry (IRENA, 2003).

Given declining renewable technology generation costs, rapidly growing electricity demand from urban-rural populations and industries, expanding local technical capacity, strong foreign investment interest, the need for low-carbon climate change mitigation, and national governments' recognition of the role of non-hydro renewable energy sources in the system, the East African region clearly illustrates the need for continued RE growth. As a result, there is a need to examine the developments and implications of a just transition to RE in the context of foreseeable economic and environmental concerns, and to propose appropriate policy recommendations to advance and accommodate the scale-up of RE sources, in addition to contributing to already existing studies (Adeyeye et al., 2021; Chambile et al., 2020; Mabea, 2020; Saadi et al., 2015).

1.2 Statement of the Problem

Due to the significant global increases in greenhouse gas emissions (GHGs) in recent years, environmental degradation and the high cost of energy generation have emerged as the most significant global challenges. Renewable Energy has been presented as suitable alternative energy source that can tackle these issues (Jae et al., 2020). Numerous scholars have examined the economic impact and implications of renewable and non-renewable energy consumption (Al-Mulali et al., 2014; Chambile et al., 2018; Cole et al., 2021; Saadi et al., 2015). Specifically, studies have demonstrated that increasing RE penetration results in decreased CO2 emissions, increased economic growth, and improved people's livelihoods and economic well-being (Chambile et al., 2018; Cole et al., 2021; Saadi et al., 2015).

However, there's little research on the aspect of overall system generation cost implication of a RE powered system for specific individual economies. Moreover, As much as there are models developed in energy economics, few have been used to assess the cost implications of alternative power generation technologies as they lack the temporal and spatial resolution to properly characterize and analyze geographic specific potentials and decrease in RE capital cost due to learning curves. The rapid growth in electricity demand annually raises concern on the electricity generation investment cost, security of supply and significant environmental effect. However previous studies and the policy documents like East Africa power pool master plan and least cost development plans modelling framework fail to capture these aspects of renewable energy transition which this research study attempts to address.

1.3 Research Objectives

1.3.1 General Objective

The general objective of the research is to explore the implication of Renewable Energy transition on cost of electricity generation and greenhouse gas emission in East African Countries.

1.3.2 The Specific Objectives

The underlying specific objectives that this research seeks to address includes:-

1. To assess the electricity generation capacity of Renewable energy and Non-renewable energy sources of electricity use in East Africa.
2. To assess the effect of Renewable energy sources of electricity generation on the Greenhouse gas emissions level.
3. To investigate the effect of Renewable energy on the total system cost of electricity generation.

1.3.2 The Research Questions

1. What is the status of current and potential electricity generation capacity of RE and Non-RE in East Africa?
2. What is the effect of RE and Non-RE on CO_2 emissions in East Africa?
3. What is the effect of RE penetration on cost of electricity generation in East Africa?

1.4 Scope of the study

This study will focus on both renewable and non-renewable energy sources that are connected to the national grid system while there are sources that are either micro grid or stand-alone systems also proving electricity in the region. The East Africa region consists of other countries such as Tanzania, Uganda, Burundi and South Sudan the study will focus on Kenya and Rwanda as an indicative of the region. Kenya being the leading amongst the other countries with an ambitious plan to implement a strategy of contributing to the use of renewables mainly from Solar, hydropower, Wind and Geothermal energy which other countries in the region have also shown potential e.g. Tanzania, Uganda and Rwanda (Jean De Dieu et al., 2016). The country also is currently the largest RE consumer with over 70% of it generation is from renewable energy resources making it suitable as a benchmark (Mabea, 2020).

On the other hand Rwanda is among the lowest energy consumer in the region just as Burundi and South Sudan but with high potential in hydro power having several projects in pipeline for the same (Rwanda Energy Sector Review and Action Plan, n.d.). It also has unique generation of a Non-RE resource potential of Peat to power at Lake Kivu which provides a great avenue to compare the resource implications economically and environmentally under various scenarios as indicative of the regional level. However as most East Africa countries share common characteristics ranging from highest unemployment levels due to limited industrialization and vulnerability related to political instability, the two countries also share almost the same virtues making it suitable indicator of the entire situation (Mabea, 2020).

Finally this research will also focus on the economic particulars and costs pertaining to both renewable and non-renewable particularly the levelized system costs and overall system costs. Additionally, study focuses on the CO_2 emission levels and its economic particulars like levelized CO_2 abatement costs for the period 2020-2050 in line with the commitment under the Paris Agreement and need to achieve global Sustainable Development Goal (SDG) number 7 and 13 of a net-zero greenhouse gas emission economy by this year 2050. While despite the importance in regional energy integration and trade in energy security and sustainability, is not part of the study scope.

1.5 Expected Outcomes and Significance of the Study

1.5.1 Expected Outcome of the Study

Basing on the case study as an indicative of broader region, the study aims at providing a quantitative and qualitative implication of renewable energy consumption on the cost of electricity generation and greenhouse gas emissions through applying the sensational capacity scenario analysis framework.

1.5.2 Significance of the Study

The research will add to the existing literature in the field of sustainable energy by assuring access to inexpensive, dependable, and efficient clean energy. Specifically the study will demonstrate how the emergence and adoption of Renewable energy in the East Africa region will create unprecedented economic opportunities particularly in the industrial and residential sector utilities currently reliant on high-cost, legacy Non Renewable energy generating assets. Moreover, the study will be a clear demonstration on how SDGs regarding environmental conservation and access to energy as well as Paris Agreement targets can be achieved in East Africa.

The study's findings will be critical inputs to regional and continental electrical infrastructure planning procedures, which may include national and regional power master plans as well as the Program for Infrastructure Development in Africa Priority Action Plan (PIDA).Finally, study will also be useful for any organization intending to implement renewable infrastructure projects since issues to be highlighted can be used to define way forward that would enhance adopting of good project implementation strategies enhanced by the consideration of various contributing variable considered in the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This part analyzes the many ideas under consideration and provides the state of the art through the perspective of various research and theories upon which this study is based. It also reviews the other literature concepts under this study as well as highlighting the gap in the past studies that the study seeks to fill. It will further lay the theoretical framework upon which this study is built on.

2.2 Theoretical Literature

This section offers theories from many authors that explain the definition of key concepts in the study. We focus on the important variables that are relevant to the objective of the research.

2.2.1 Renewable Energy source of Electricity

Renewable energy (RE) is described as "a flow of energy that cannot be depleted by usage" and includes both old and emerging renewables such as contemporary biofuels, wind, solar, small-scale hydropower, marine, and geothermal energy (UNIDO, 2016). Thus, it is any type of energy resource that may be regenerated by natural processes at a rate equal to or greater than the rate at which it is used (Cole et al., 2021). According to the German Advisory Council on Global Change, renewables have "overall potential that is in principle endless or inexhaustible, and is CO2-free or -neutral" (Spittler et al., 2021). These definitions clearly depict the general overview of renewable resources and their characteristics.

RE resources are powered by natural gas and are characterized by low operating costs but high capital expenditures. The distinctive qualities of RE include its intermittent nature, which provides variations in net load due to its reliance on changeable weather conditions, such as wind and solar (Verzijlbergh et al., 2017). The concept of RE transition, on the other hand, revolves around the subject of climate change and the need to eliminate the costly usage of fossil fuels. The underlying goal of this motive is to lessen the associated environmental consequences while also increasing energy resource capacity to fulfill the ever-increasing demand in the future (Mabea, 2020). These changes in the energy mix asserts that there is a transition from use of fossil fuel and typically imply that there is development of infrastructure expanding production of new source and the established ones are being faced out. Brown identifies the needs for the transition as need to combat climate change, need to meet future generation demand and energy security (Brown, 2015).

However there is need for policy that guide the transition for example in European Union, a policy instrument has been developed to facilitate transition where it advocates greening accounting mostly in electricity markets and the importance of drafting frameworks in terms of policy that promote RE adoption through Research (Newbery, 2016). Nonetheless, as the change occurs, it is critical to address the process for capacity growth. Neuohoff believes it is prudent to build a capacity strategic reserve and underlines the importance of well-integrated and coordinated cross-border strategic reserves in order to improve energy security (Neuhoff et al., 2016).The aspect of the timing of switching was analyzed extensively by Amigues et al where emphasized on transition based on gradual systematic investment and advocate for long term planning to increase maximum utility from the RE resource (Amigues et al., 2015).

2.2.1.1 Current status of Electricity Generation from Renewable Energy sources

With the global focus on accelerating climate mitigation efforts, particularly through divestment from fossil fuels to the RE sector, the issue of a RE transition has risen to the forefront of international policy debate, fueled primarily by trade unions and civil society organizations (CSOs) from around the world (IRENA et al., 2020). Currently, while global RE consumption has been expanding at a pace of 5% per year (between 2009 and 2019), it only accounts for 29% of total energy consumed now (REN21, 2021).The Sub Saharan Africa consists of majorly hydropower Renewable resources where in the East Africa region, renewable electricity accounts for approximately 70% of the region’s total installed grid-connected power generation capacity (IRENA et al., 2020).

International Renewable Energy Agency (IRENA) depicts that 11GW of the installed capacity of 15GW in East Africa is accounted by renewable energy sources (IRENA, 2021). Kenya is leading the region in the tack where their electricity generation mix is composed of 74.4% Renewable energy (RE) while Rwanda accounting only 54.6% (Renewable Agency, 2016). While hydropower continues to account for the majority of installed renewable energy capacity in the region, its relative share has declined from 92 percent in 2010 to 67 percent today as other renewable technologies such as solar

PV, geothermal, and wind energy, among others, have become more competitive. Furthermore, with insufficient significant, reasonable investments in refurbishing existing hydropower plants, this share decline will only accelerate (IRENA et al., 2020).

2.2.1.2 Potential status of Electricity Generation from Renewable Energy sources

Potential of an energy resource refers to the availability of the resource for exploitation in electricity generation (Saadi et al., 2015). A variety of feasibility studies have been conducted to examine the potential of both renewable and nonrenewable energy for the growth and development of the energy sector, the expansion of power access, and consequently the long-term development of countries' economy (IRENA, 2003). The East African states collectively have a vast renewable energy potential that has only been marginally exploited to date; for example, hydro power has the largest potential of 13.5Gw but only 15% has been exploited, with Kenya and Tanzania having the highest potentials of 4.5Gw and 4.8Gw, respectively (REN21, 2021).

The region boasts of the highest solar energy potentials globally since it has the highest levels of solar irradiance, with a year round isolation between 4-6.5Kwh per square meter per day (IRENA, 2003).Geothermal energy potential is largely available along the East Africa Rift Valley with an estimated potential of 15.8Gw;Kenya has the highest potential in geothermal energy of about 10Gw while Rwanda has an estimated amount of 300Mw (IRENA, 2003). Another RE potential in the region according to the literature is the Wind energy which sites identified for large scale deployment is found in Kenya and Tanzania whose potential exceeds 1Gw (UNIDO, 2016).

2.2.2 Non-Renewable Energy sources of Electricity

Non-renewable energy resources are those that can be exhausted because they do not replenish themselves at a sufficient pace to allow for sustainable economic extraction in meaningful human time periods (Jean De Dieu et al., 2016). These includes energy resources as Coal, Peat, Oil thermal natural gas among others which are burned to generated energy (Koengkan & Fuinhas, 2020).They are formed underground from animal and vegetal remains through process of transformation which evolve over a million years and distributed unevenly around the world which requires a systematic process required to find and exploit them (Bhattacharyya, 2019).

2.2.1.1 Current status of Electricity Generation from Non-Renewable Energy sources

Despite the RE increase in the past years globally, Non-RE energy consumption still account for approximately 65 % of total electricity energy generated with (World Bank, 2015). Sub Saharan Africa still has the highest Non-RE electricity generation at 64.1% of its electricity generation (IEA, 2019b). Regionally, East Africa still has about 35% of the total electricity generated from Non-RE mainly from diesel or heavy fuel oil that are costly and polluting (Mabea, 2020).

Specifically, Kenya which is the largest economy in the region, generates electricity from fossil fuel sources that accounts approximately 14.1 % of the total electricity generation (KPLC, 2021). While on the other hand Rwanda the least and fastest growing economy in the region also still generate electricity from Non-RE energy accounting for 38% (REG, 2020). There are also plans to expand generation from peat-fired power to 44% capacity in the country which will have economic lifetime beyond 2050 (IRENA, 2021).

2.2.1.1 Potential status of Electricity Generation from Non-Renewable Energy sources

The potential of Non-RE refers to the future availability of the resource for exploitation in electricity generation i.e. the available reserves that can be explored and used to generate electricity for the future demand. According to International Energy Agency (IEA), worldwide energy consumption has been on an increasing trajectory from the last few years owing to the increased economic growth and energy demand in tandem (IEA, 2018). According to the German energy industry organization, non-renewable energy output is likely to drop as renewable energy production climbed by 44 percent in the first half of 2019, up from 39 percent in the first half of 2018. Onshore wind accounted for 19% of total electricity production, followed by biomass and solar PV, each accounting for 8% (BDEW, 2019).

India, on the other hand, continues to rely largely on non-RE, with coal demand increasing by 9.1 percent in 2018-2019 (Y. Chang et al., 2021). Its projected that Non-RE will increase in future as the consumption from the power sector uses three-quarters of the coal has been rising by 6.6% in 2017-2019 (Y. Chang et al., 2021).

According to the International Energy Outlook, global electricity energy generation from all fuel sources will increase until 2040, with the exception of coal, which is expected to remain steady (IEA, 2018). In Sub Saharan Africa specifically East Africa, the case is the same as in the master plans and countries least cost development plan still prioritize Non RE potential to bridge the gap between the electricity supply and demand in the region accounting for 35% of the total future planned generation in the region (EAPP, 2014).

Kenya, on the other hand, does not have a known amount of commercial oil, coal, or natural gas resources, but exploration is continuing. As a result, the whole specification of such fuels is obtained through importation (Takase et al., 2021). The preliminary exploration results are promising; early part in 2007, ten wells were drilled in the Mui Basin with positive findings indicating the potential presence of industrial volumes of gas, and a 1050 MW coal-fired power plant was proposed for Lamu, Kenya's northern coast along the Indian Ocean (M. Chang et al., 2021).

Methane gas is a substantial non-renewable resource in Rwanda, with an estimated 50 billion cubic meters of recoverable methane equivalent to 40 million tons of petrol (TOE) lying beneath Lake Kivu under 250 meters of water (Hakizimana & Kim, 2016). According to studies, 39 billion cubic meters (cum) Standard Temperature and Pressure, STP) of methane gas reserves are possibly extractable out of the 55 billion cum (STP). Since 1963, the small methane extraction pilot unit at Cape Rubona with a capacity of 5000 cum of methane per day at 80 percent purity has clearly demonstrated the technical and economic feasibility of methane gas exploitation, and the resource is estimated to be sufficient to generate 700MW of electricity for 55 years, with Rwanda's share being 350MW (Hakizimana & Kim, 2016). Peat is also a readily available resource, with an estimated 155 million tons of dried peat scattered across a 50,000 ha region that has been theoretically calculated to sustain up to 50Mw of energy output if exploited (Hakizimana et al., 2016).

2.2.2 Energy Resources and Greenhouse Gas Emissions

Global warming and climate change have been a popular issue for some years, and they are occasionally manifested by floods or droughts, making it one of the top policy concerns of many states to take action before it is too late (Vural, 2020). Chen et al confirms that an increase in carbon emissions is the primary cause of global warming (Chen et al., 2018). However, most of the emissions arises from burning of fossil fuel like coal and gas which deplete the quality of the environment (Paramati et al., 2017).Researchers, scientist and experts have recommended and advocated for carbon price as way to reduce the emissions from the fossil fuel thus transitioning to a low-carbon and resilient economy powered by RE resources (Steffen, 2020). A study by Lin and Lia alludes that high energy generation costs weakens the ability and the capacity of markets to reduce the greenhouse gas emissions while lower cost of energy generation leads to higher urge to reduce emissions (Lin & Jia, 2019).

However understanding potential factors affecting the greenhouse gas emissions in Africa and particularly is important in order to design the appropriate policies to curb the situation and promote sustainable development. Particularly taking appropriate measures to address the environmental degradation in the region becomes imperative considering harsh climatic condition and the population densityIn Africa, coal energy–driven generation with low uptake of renewable energy, combined with a lack of electricity supply, is affecting the operational costs of small and medium-sized businesses, prompting firms to switch to gasoline energy generation, which emits a large amount of greenhouse gas emissions (Chakamera & Alagidede, 2018).

As much previous studies have appreciated the fact there is need to address challenges that confront the environment as a result of climate change brought by greenhouse gas emissions they have overlooked the predictive power of price and cost of Renewable energy in mitigating the greenhouse gas emission. The focus and state of the art in the studies have been how energy consumption,GDP, industrialization, energy intensity, financial development and renewable energy affects and predict the Greenhouse gas emissions in the economies (Abid, 2016; Ben Jebli et al., 2015; Shahbaz et al., 2015). Understanding the potential factors and drivers of the greenhouse gas emissions is vital in creating sound policies towards sustainable energy development. However despite emphasis placed on the contribution of current trends of renewable energy costs and prices on greenhouse gas emission reduction at global level little attention has been paid to the regional developing countries. For example an energy price has different effect on carbon emissions in USA depending on the market spectrum while China energy price has an indirect effect on carbon emissions.

The various types of greenhouse gases can be described from point of view of the sources and lifetime in the environment. Specifically, Methane gas refer to the emissions from human activities such as raising livestock, leaks from the natural gas as well as the natural process in soil and chemical reactions (EPA, 2019). It has a shorter lifetime in the atmosphere compared to carbon dioxide but very efficient than carbon dioxide in trapping radiation (IPCC, 2013). Globally 65% of the CH_4 emissions are from human activities (GCP, 2020).Nitrous oxide (N_2O) is another type of GHG whose emissions is estimated to account for about 10% of the global emissions, of which most are deriving from human agricultural activities (De Klein & Eckard, 2008). Greenhouse gas emissions from the agricultural sector that are related to grazed land and manure comprise N_2O (Kebreab et al., 2006).

Finally, fluorinated (F-gases) are the long lasting and most potent greenhouse gases which are emitted by human activities which include production of fluorinated (F-gases) and the supply of the fluorinated GHG (US EPA, 2020). Thus, unlike other greenhouse gases, F-gases have no natural origins because they are emitted as a byproduct of their use as ozone-depleting alternatives (e.g., as refrigerants) and a range of industrial activities such as aluminum and semiconductor manufacture (EPA, 2019). Because fluorinated gases have extremely high global warming potentials (GWPs) in comparison to other greenhouse gases, modest air quantities can have disproportionately big effects on global temperatures (US EPA, 2020).

2.2.3 Carbon dioxide (CO_2) Emissions

According to the International Panel on Climate Change (IPCC), this is the principal driver of global warming, accounting for more than 80% of total emissions generated by human activities such as the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation (EPA, 2019). These human activities alter the carbon cycle by releasing more CO2 to the atmosphere and interfering with natural sinks' ability to take and store CO_2 from the atmosphere, such as forests and soils (Kebreab et al., 2006). Aydoan and Vardar investigated the role of renewable energy and the link between per capita CO_2 emissions, economic growth, and agricultural value added and non-renewable energy consumption in the E7 countries, finding a negative relationship in the long run. The policy implication suggested is that the E7 countries should continue to increase the share of renewable energy for the sake of agricultural growth, thus validating the need to reduce fossil fuel (Aydoğan & Vardar, 2020).

In his study, Zoundi combines a panel cointegration analysis with a set of robustness tests to assess the short and long run impacts of renewable energy on CO_2 emissions, as well as validating the Kuznets Environmental Curve hypothesis for 25 selected African countries from 1980 to 2012, where the overall estimations strongly revealed that renewable energy has a negative effect on CO2 emissions, coupled with an increasing long run effect, remains an efficient and effective option (Zoundi, 2017). It is generally known that the significant use of non-renewable energy sources in generating power (e.g., coal, oil, natural gas) is a major contributor to environmental dangers through releasing carbon emissions (Hanif et al., 2019).Because decreasing greenhouse gases (GHGs) emission including carbon emissions require global cooperation, countries came together and signed Kyoto Protocol in 1997 which showed a roadmap towards zero carbon economy (Vural, 2020).

Developing countries are projected to demand a higher proportion of the world energy production approximately by 40% by 2040 (IEA, 2018).However, if the global warming continues to rise at the current rate, it is expected to reach 1.5C between 2030 and 2052 and comparing climate related risks for the global warming due to carbon emissions, it shows that contraction in yields of cereal crops will be severe especially in Sub-Saharan Africa, Southeast Asia, Central and South America (IPCC, 2018). Although Africa contributes less to environmental pollution than other continents, it suffered a lot from climate change and global warming (Zoundi, 2017).

The electrical sector accounts for approximately 14% of overall energy-related CO2 emissions in East African countries (IEA, 2019b).Per capita emissions from the regions electricity sector is estimated to be $0.20MtCO_2$ which is almost seven times higher in the European Union (IEA, 2019b).This is a consequence of higher per capita electricity consumption combined with the dominant use of fossil fuel in electricity energy generation thus decarbonization of this sector should be of top priority in the policy formulation (Steffen, 2020).

2.2.4 Cost of Electricity Generation

Generally in economics, cost refer to the use and consumption of real resources or production factors such as (land, materials, labor time, buildings, utensils, etc.); all costs incurred down to "opportunity costs," i.e., the results foregone by assigning the real resources and factors to a specific project, making them unavailable for the next-best project (Verbruggen et al., 2010). In this context the cost of electricity generation refers to the constant (in real terms) cost for the a unit of power that will equate the net present value of revenue from the same unit of power output and it depends with engineering factors across various generating resource technologies i.e. levelized cost of electricity (LCOE) (Borenstein, 2012).

Further, because generation plants are heterogeneous in location, architecture, and other factors, even plants with similar technology will not have the same LCOE.RE generation require very large investment and thus there's need to internalize the costs of producing a unit of electrical energy from these technologies through the LCOE (Hafner et al., 2019). Due to the growing requirement to deploy renewable energy sources of power, studies on the cost generation from many viewpoints have been conducted, informing policymakers and investors on the cost and value of various RE technologies (Borenstein, 2012).

The LCOE is the most convenient metric to compare two alternatives of electricity sources in quest to solve the optimization problem faced by public decision makers on whether to supply RE via the grid, off grid or the min-grid (Hafner et al., 2019). Similarly, estimation of RE generation cost have become the integral part of long term energy modelling setup that compare capital intense renewable energy with less capital intense non-renewable energy technologies making a significant part of lifecycle cost of RE projects by expressing cost of capital in terms of the LCOE in various countries (Steffen, 2020). RE is characterized by high upfront costs and thus making the financing conditions highly relevant but with continuous fall in the costs of renewable electricity generation coupled with supporting storage technologies will be the driving force of the energy transition in Africa.

In fact according to Eom and Haegel solar PV has already become the least cost energy source in many countries and regions of the world and this is expected to continue declining (Haegel et al., 2017) (Eom et al., 2015). Similarly storage cost is projected to continue declining definitely making 100%

RE electricity systems highly cost competitive in the future (Schmidt et al., 2017). It is also forecasted that at 100% RE penetration the range of LCOE for countries will be 27–70 €/MWh around a global average of 52 €/MWh and uncertainty range of 45–58 €/MWh for 2050 with lowest LCOE is reached in Iceland, a country with excellent geothermal energy and hydropower potential (Schmidt et al., 2017).Needless to say that after 2050 the cost will continue to decline a further 20% due to reinvestments in RE capacities (Schmidt et al., 2017).

2.3 Empirical Review of the Study

There has been several studies focusing on the impact of RE transition and creation of possible RE pathways of the power system using varied exploratory approaches and models (Adeyeye et al., 2021; Borenstein, 2012; M. Chang et al., 2021; Cole et al., 2021; Hakizimana et al., 2016; Koengkan & Fuinhas, 2020) among others. This has been done at national or regional level and it is typically through application of energy systems models and approaches which are classified based on the methodology i.e. economic equilibrium optimization, analysis framework (top-down and bottom-up), hybrid and sectoral coverage (Musonye et al., 2020).

Globally, the effect of RE and Non-RE consumption on economic growth and energy system emission impact was explored. Usama applies panel gross domestic product model which shows cointergation of the RE, Non-RE and economic growth but with RE having a more significance than Non-RE in promoting economic growth in the long run (Al-Mulali et al., 2014). Similarly, in China, Fang determined that boosting renewable electricity consumption will enhance the country's economic growth and income level (Fang, 2011). Furthermore, Apergis and Payne discovered that renewable energy has a long-run effect on economic growth and that there is a bi-directional causal relationship between factors in emerging economies (Apergis & Payne, 2010). Thus, the use of renewable energy reduces CO_2 emissions while increasing economic production across economies; at the same time, economic expansion, trade openness, and urbanization increase CO_2 emissions (Koengkan & Fuinhas, 2020; Paramati et al., 2017).

The impact and significance of RE in achieving the Paris Agreement on climate change has been investigated at the regional level. Zwaan used the Times Integrated Assessment Model - Energy Research Center (TIAM-ECN) to assess the impact of the Paris Agreement climate change goal on future renewable energy resource absorption over the 2010–2030 period, demonstrating that increasing RE by 4% per year results in a 20% reduction in emissions compared to 2010 levels in Sub-Saharan Africa (Zwaan et al., 2018). While Ouedraogo projects the impact of renewable energy and efficiency measures in demand-supply on carbon emission investment and investment cost using the Long Range Energy Alternative Planning (LEAP) model, which runs from 2015 to 2040, to simulate the various technology pathways that can be used to meet different demand scenarios for the region (Ouedraogo, 2017b).

Researchers have also focused on the implications of potential RE integrated power system scenarios. Uhorakaye uses a hybrid approach to assess the alternative power supply scenario for Rwanda that would be resilient to combat climate change between 2012 and 2050, highlighting the importance of RE in reducing emissions and meeting energy demand in all sectors by integrating 65 percent RE into the system by 2030 (Uhorakeye, 2016). In Tanzania, a study by Kichonge links MESSAGE and MAED in a bottom-up simulation and optimization approach, with the aim of exploring various energy supply pathways to meet Tanzania’s electricity demand trajectory and contribution of RE in across various seasons between 2010 and 2040 (Kichonge et al., 2015).

On the other hand, least cost investment options and implications of a diversified RE integrated power system has also been addressed by Guta and Beorner. They applied a Dynamic Linear programming model to evaluate the role of RE investment and its implication on land prices in Ethiopia where they show increase in cost by integrating RE in the system (Guta & Börner, 2017).In Kenya Carvallo explores low carbon development pathways for Kenya from 2020 to 2035 applying SWITCH bottom-up optimization model where analyzed five scenarios considering geothermal sources, coal power and imposing carbon emission tax also showing that RE results in low emission levels than Non-RE (Carvallo et al., 2017).While the cost implications and associated emissions from the three possible least-cost solution pathways applying LEAP model shows that RE increases the overall system cost and reduces carbon emission compared to Kenya governments Least Cost Development Plan (LCDP) (Musonye et al., 2020).

In addition, some studies provide overview of current status of the power system RE penetration and its potential. For example in Sub Saharan Africa, though there has been 60% increase in RE penetration over the past few years, its relative share is only 2% showing that there's vast potential for RE to be explored in the region thus there's need to call for action for necessary investment and cost implications in the sector (Chambile et al., 2018, 2020; Hakizimana et al., 2016). The abundance of the RE has triggered the international bodies to advocate for its deployment owing to its low carbon emission threshold as a way to limit global warming. Studies have shown that penetration of Solar and Wind makes it more imperative considering that the generation costs of the latter has been consistently declining by 60% and 25% respectively (Saadi et al., 2015) (IRENA, 2021) (Adeyeye et al., 2021).

However contrary findings have been provided the on the effect of RE (Apergis & Payne, 2010) (Borenstein, 2012). For example using Fully Modified Ordinary Least Square (FMOLS) model, findings depicts a positive impact of RE on CO_2 emission level and attributed to lack of financial incentive that do not encourage RE technologies and consequently consumption of green energy (Apergis & Payne, 2010, 2014) As a result, with a renewed emphasis on the Sustainable Development Goals, studies on the influence of electricity energy consumption and CO2 emissions on economic growth remain critical in order to give evidence-based energy policy and institutional decisions.

Specifically interest has been the nexus between electricity consumption, emissions and economic variables.Empirically, several studies have attempted to show the probable connection between these variables most of them concentrated on testing the environmental kuznet curve that basically hypothesises the environmental quality,electricity consumption and economic growth nexus and casuality. However despite such considerable ammount of exant studies, accounting for effects of quality of electricity generation on economic and environmental aspects is still lacking in the empirical literature as shown in the summary of studies table 1 below.

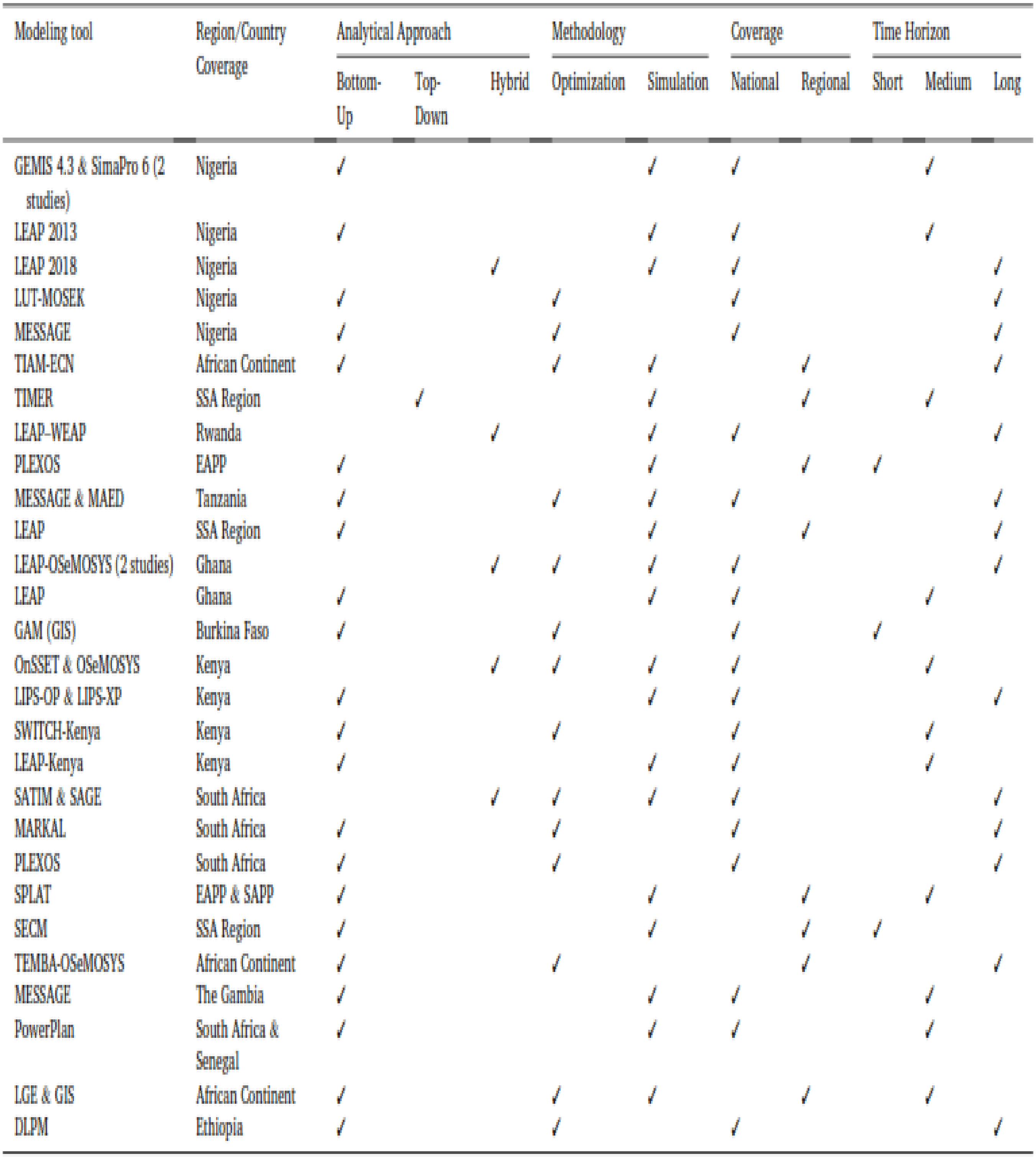
Table 1 summary of other previous studies that applied various energy models reviewed

Model Name and Acronym	Study and Reference

Regional Energy Deployment System (ReEDS)	Modelling and exploring the impact of RE transition in a least cost approach with no policy drivers. The findings shows that RE penetration in US will be 54% with high CO_2 emissions and increasing generation cost if penetration increased by 2050 (Cole et al., 2021).
Model for Energy Supply Strategy Alternatives and General Environmental impacts (MESSAGE)	Modelling energy supply options for electricity generations in Tanzania where study shows that the least cost solution will be dominated by Non-RE while at low discount rate and renewable energy penetration policy will favour Wind and Natural gas in the system (Kichonge et al., 2015)
Long Range Energy Alternative Planning (LEAP)	Africa energy future: where author projects the impact of renewable energy and efficiency measures on demand-supply, carbon emission investment and investment cost (Ouedraogo, 2017b).
Open Source Energy Modelling System (OSeMOSYS)	Authors developed least- cost system configurations to examine power system investment based on trade potential and findings shows that enhanced RE integrated grid network can alter Africa generation mix and reduce generation cost (Taliotis et al., 2016)
Systems Dynamic Model	The authors explores the implication of RE dynamics of Hydro and Geothermal resources in Kenya where he shows that excessive utilization of Geothermal resources can lead to production losses while climate change can significantly affect availability of Hydro power in turn leading to high electricity generation cost (Spittler et al., 2021)
Times Integrated Assessment Model - Energy Research Center (TIAM-ECN)	Authors provide an RE integrated assessment of pathways for low-carbon development in Africa (Zwaan et al., 2018)
System Planning Test (SPLAT)	The authors evaluate the implications of regional integration to promote renewable energy-fueled growth, with findings indicating a reduction in overall system costs and CO2 emissions, owing primarily to the shift from high-cost fossil fuel sources to a combination of hydropower in the

	coupled with high-quality wind and solar potential in East Africa (Saadi et al., 2015)
Market and Allocation (MARKAL)	Examined South Africa's potential energy evolution toward more sustainable and environmentally friendly energy sources. Models a variety of policy possibilities for the years 2000–2025. The study simulates the effects of demand and supply side policies on sustainable energy development, as well as the impact of increasing the quantity of imported power on carbon emissions and investment costs (Winkler, 2007)
Long Range Energy Alternative Planning (LEAP)-Kenya	The author examines the costs and GHG emissions associated with three potential development paths: the government's Least Cost Development Plan, natural gas, and renewable energy scenarios. When compared to the government's lowest cost plan, the RE scenario results in higher generating costs and lower GHG emissions (Musonye et al., 2020).
Long-range Energy Alternative and Planning - Water Evaluation and Planning system (LEAP-WEAP)	The author evaluates a power supply scenario that would be resilient to the effects of expected climate change and ensure the security of Rwanda's power supply with the least emissions towards 2050, and discovers that an alternative RE scenario will result in a 40% reduction in CO2 emissions and a levelized cost of US$Cents 13.13/kWh compared to the business as usual scenario with a cost of US$Cents 13.13/kWh. (Uhorakeye, 2016)
Solar and Wind energy Integrated with Transmission and Conventional sources (SWITCH)	The author analyzes the implication of various levels of RE and coal planned generation compared to carbon tax imposed scenario where the findings shows that production cost will increase and higher under coal scenario compared to the latter (Carvallo et al., 2017)

Table 2 classification of models applied in reviewed studies



Modeling tool	Region/Country Coverage	Analytical Approach			Methodology		Coverage		Time Horizon		
		Bottom-Up	Top-Down	Hybrid	Optimization	Simulation	National	Regional	Short	Medium	Long
GEMIS 4.3 & SimaPro 6 (2 studies)	Nigeria	✓				✓	✓			✓	
LEAP 2013	Nigeria	✓				✓	✓			✓	
LEAP 2018	Nigeria			✓		✓	✓				✓
LUT-MOSEK	Nigeria	✓			✓		✓				✓
MESSAGE	Nigeria	✓			✓		✓				✓
TIAM-ECN	African Continent	✓			✓	✓		✓			✓
TIMER	SSA Region		✓			✓		✓		✓	
LEAP–WEAP	Rwanda			✓		✓	✓				✓
PLEXOS	EAPP	✓				✓		✓	✓		
MESSAGE & MAED	Tanzania	✓			✓	✓	✓				✓
LEAP	SSA Region	✓				✓		✓			✓
LEAP-OSeMOSYS (2 studies)	Ghana			✓	✓	✓	✓				✓
LEAP	Ghana	✓				✓	✓			✓	
GAM (GIS)	Burkina Faso	✓			✓		✓		✓		
OnSSET & OSeMOSYS	Kenya			✓	✓	✓	✓			✓	
LIPS-OP & LIPS-XP	Kenya	✓				✓	✓				✓
SWITCH-Kenya	Kenya	✓			✓		✓			✓	
LEAP-Kenya	Kenya	✓				✓	✓			✓	
SATIM & SAGE	South Africa			✓	✓	✓	✓				✓
MARKAL	South Africa	✓			✓		✓				✓
PLEXOS	South Africa	✓			✓		✓				✓
SPLAT	EAPP & SAPP	✓				✓		✓		✓	
SECM	SSA Region	✓				✓		✓	✓		
TEMBA-OSeMOSYS	African Continent	✓			✓			✓			✓
MESSAGE	The Gambia	✓				✓	✓			✓	
PowerPlan	South Africa & Senegal	✓				✓	✓			✓	
LGE & GIS	African Continent	✓			✓	✓		✓		✓	
DLPM	Ethiopia	✓			✓		✓				✓

Source: Authors illustration based on literature

2.4 Critical Review and Gap Identification

This study builds on the previous literature reviewed. While they shed significant lights on this study, they had some gaps which this study seeks to fill. First, most of the studies are focused on the developed countries and economies. For instance,(M. Chang et al., 2021; Cole et al., 2021; Verbruggen et al., 2010; York & Bell, 2019) explored the effects and implications of Renewable energy transitions in developed countries. While (Kichonge et al., 2015; Musonye et al., 2020; Neuhoff et al., 2016; Uhorakeye, 2016; Zwaan et al., 2018) on the other hand focused on the exploration of least cost optimal transition implications and timing between turning off the fossil fuel and running renewables where they estimate least cost investment decision needed to expand power system subject to meeting the underlying demand. Despite significant increase in interest to a low-carbon economy in developing and least developed countries, evidence of developing economic models to assess implication of low-carbon is really sparse.

East African countries have fallen behind in developing low-carbon transition assessment models and tools. While some studies have been focusing on effects of RE deployment, focus has only been to show RE impact on various macro-economic conditions and environmental factors. For example several studies have applied LEAP, MESSAGE, SWITCH, TIMES and Econometric models to show that nexus between RE, CO_2 emission, economic growth, human welfares and economic well-being of people.While such studies are relevant they have generally focused on few social and macro-economic conditions and scenarios which may evolve in future. Inevitably there's little research and approaches accounting to high degree of uncertainty on important factors like resource potential and associated system generation cost for specific individual economies. Thus considering much anticipated RE deployment in future, it's important to capture and unravel the RE dynamics hitherto ignored by previous researchers such as geographical diversity, the decline in RE capital costs due to learning curves as well as the seasonal power demand load capacity and its overall system cost and environmental implication when planning for future power capacity expansion.

2.5 Conceptual Framework of the Study

It is fundamental to have a foundation for decision on variables to predict the implication of Renewable energy transition. This section relates the various model input variables i.e. the renewable energy capacities, non-renewable energy capacities; electricity demand load profile as well as the potential generation, transmission & distribution capacity with the expected scenario output variables such as CO_2 emission levels, the system levelized cost of electricity generation and least cost supply options.

To realize it, this study adapted the (Saadi et al., 2015) and (IRENA, 2021) model approach in order to answer the vital research objectives. Nonetheless, some features were not analyzed since they were not in scope of the study while other variables were included during the model feature calibration and data selection to increase the novelty in the study. The conceptual framework applied in the research study is shown in figure 1 below.

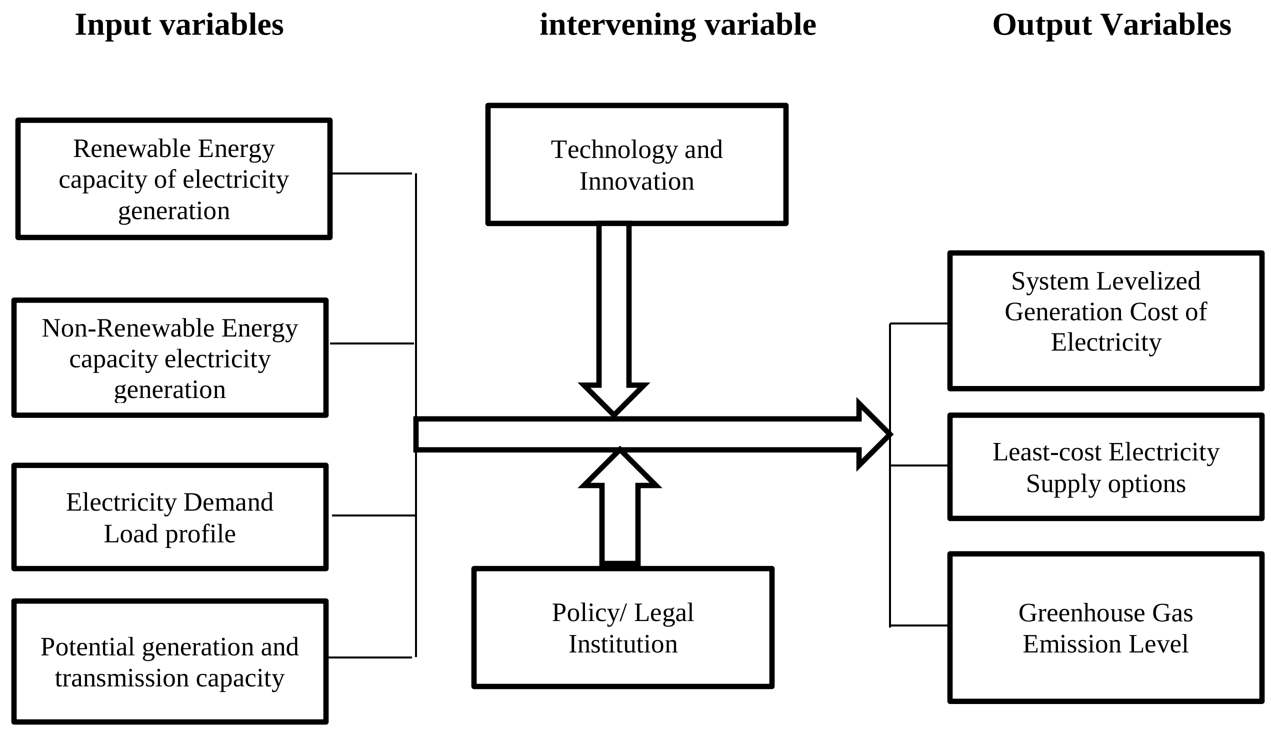


Figure 1 Conceptual Framework modelled after (Saadi et al, 2015)

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

This section discusses the methodology and approaches utilized in this study which include data description and its sources, data calibration metrics and the System Planning Test model assumptions. The subsections below highlights the important features of this capacity scenario development tool in terms of input parameter assumptions, values adopted for the variables as well as scenarios adopted in the study. The general illustration of the process followed to assess implication of RE transition on cost and CO_2 emissions is captured in figure 2 below.

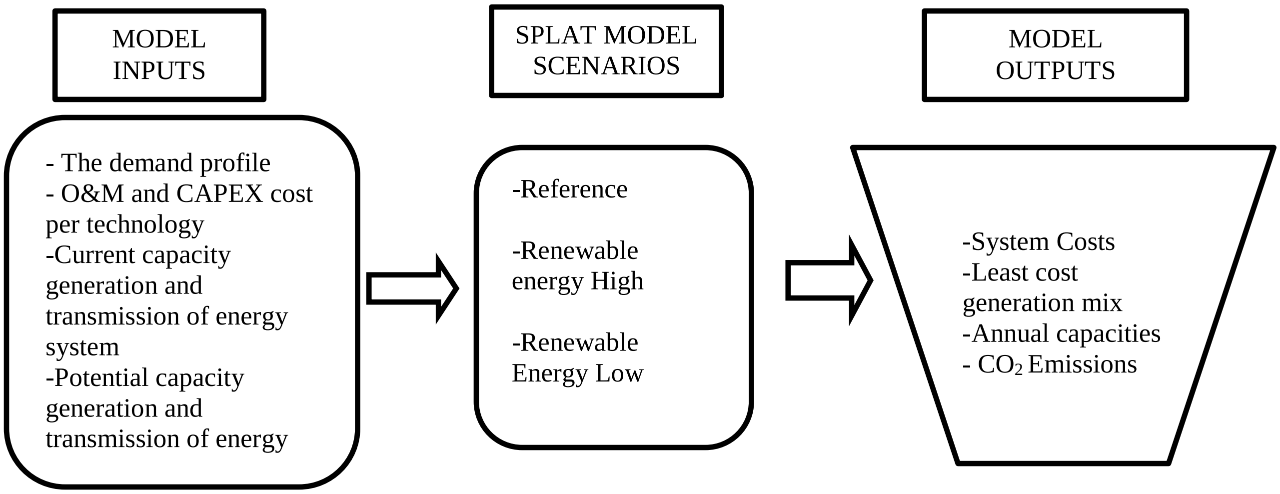


Figure 2 A schematic view of the methodology.

3.1 The System Planning Test Model

The system planning test (SPLAT) model operated at the Model for Energy Supply Strategy Alternatives and their General Environmental impacts (MESSAGE) software platform is an energy systems model that can be employed in analyzing energy mixes based on a number of techno-economic and socio-economic conditions and has capacity to model both energy demand and energy supply at global, regional and national levels (Saadi et al., 2015). The SPLAT model is a capacity scenario expansion modelling tool established by IRENA built on MESSAGE modelling platform software. The latter was created by International Institute for Applied systems Analysis (IIASA) and adapted by the international Atomic energy Agency (IAEA) for national planning purposes being a multi-year dynamic bottom-up energy system model that uses both linear and mixed integer optimization approaches (IAEA, 2017).The SPLAT model has been endorsed by 5 African power pools as official planning tool for the upcoming continental power system development that include Eastern Africa Power pool, an initiative spear headed by Africa Union Development Agency (IRENA, 2021).

The motivation to choice of this model is based on fact that most developing and least developed countries have been applying end-use modelling framework approaches for energy demand and supply analysis for example , top-down approaches mostly have been applied in assessing economy-wide responses to policies and other driving variables through the end-use behavior and historical macro-economic variables (Ouedraogo, 2017a).Similarly using the bottom–up optimization, least-cost technology mix has been determined, and the cost and emission consequences of several generation-mix scenarios have been assessed. (Pandey, 2020). However, these models are limited in their policy implication and prescription since sometimes fails to include the most important aspects of developing and least developed economies, such as the majority of East African countries which this model captures endogenously.

3.1.1 Electricity Generation

The model considers electricity generation capacity, with existing RE and non-RE power plant capacities being added into the model as a reference. Additionally, committed future projects are added, whereas planned uncommitted candidate projects can only be selected if they are assessed to be part of the most cost-effective solution. A number of centralized generation alternatives are examined in this study. These include, in particular, centralized diesel systems linked to the transmission network, Large hydro (dam or run-of-river) connected to the transmission network, heavy fuel oil-fired power plants connected to the transmission network Small or mini-hydro projects (less than 10 MW) that can only offer electricity to remote areas Biomass-fired plants connected to the transmission network, Solar PV and Geothermal facilities connected to the transmission network, and Onshore wind facilities with two options: one with an average capacity factor of 25% and one with a capacity factor of 30%. The daily capacity profile was created by averaging the RE capacity profile with current meteorological data. The capacity factor sets a technology's hourly generation endogenously within the model; for example, solar PV cannot produce at night, whilst other technologies such as wind, geothermal, and biomass cannot generate beyond their capacity factor. It's needless to say that capacity factors considered in the research are location specific. The estimates on resource current and potential generation and transmission capacities are proxied using the maximum existing and committed project capacities which are site specific as per the regions energy master plan (EAPP, 2014).

3.1.2 The Cost of Electricity Generation

As shown, this model uses a general energy system cost-minimization method that may be used in either a multi-country mode (where trade is considered endogenously as part of the cost-minimization) or a single-country mode (where international power trade is defined exogenously as model input) as shown in (Eq. 1 and Eq.2). For this analysis, the model will be in a single-country mode, inferring that specific country generation, transmission and distribution investment costs for 2 countries are optimized exogenously by the model.

$$Min \sum cost * (X_{sit} + Y_{it}) \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Subject to

$$\sum_{i=1}^{i=n} \eta_{it} X_{it} \geq D_{st} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2)$$

To provide more insights on this, the model is calibrated to replicate the existing power generation systems for initial years from 2020 such that the model is run to assess how the projected demand at scenario(s) at year (t) (D_{st}) can be met cost-optimally through various electricity technology dispatch and capacity build from a catalogue of existing, committed and generic potential technologies (X_{sit}).

However, the study's key cost variables, the levelized cost of electricity (anticipated LCOE) and overall system cost, are estimated based on assumptions and may be found in Annex 2. The cost calculations are the same for all power plants, and the calculation framework is based on that published in (Saadi et al., 2015). The model determines the cheapest technology for dispatch or construction based on the projected LCOE, as stated in equations 1 and 2. As displayed in equation 3, the model calculates the total system LCOE (G_t) as a function of power plant capital cost (k_{it}) for specific technology (i) at year t, Operation and Maintenance (O&M) (O_{it}) for technology (i) at year t and fuel cost (S_{it}) for technology (i) at year t over plants life time (l), capacity factor (e_{it}) for technology (i) at year t, discount rate (r) and hours of operation (h).

$$G_t = {K_{it} + O_{it} + S_{it}} \Big/ \sum_{t=1}^{l} \frac{h_{it} \times S_{it}}{(1+r)^t} \text{ ………………… (3)}$$

3.1.3 The Electricity Generation CO_2 Emissions

The CO_2 emissions from electricity is calculated also endogenously within the model calibrated based on the emission factors as adapted from the latest IPPC reported data (IPPC, 2018). Thus the model calculates the system derived CO_2 emissions as shown in equation 4 below where CE is the CO_2 emission from the system at year t, ED represents the electricity demand while EF shows the emission factor for a specific technology.

$$CE_t = ED_{st} \times EF_{it} \text{ …………………………………….. (4)}$$

Furthermore, the cost of attaining these emission reductions will be compared to the value of CO2 emissions. To make that comparison, the system cost and CO2 emissions are converted into a levelized CO2 abatement cost across the SPLAT model horizon. As stated in equation 5, this is the difference in total system cost divided by the difference in CO2 emissions between sequential RE penetration scenarios.

$$LCAC = TSC_{S1} - TSC_{S2}/CE_{S_1} - CE_{S2} \text{ ………………… ..(5)}$$

Key:

LCAC- Levelized CO_2 Abatement Cost

TSC - Total system cost

CE - Carbon dioxide Emission

3.2 SPLAT Input Assumptions and Scenarios

This section discusses model calibration under set of input assumptions which reflect the various future expectation of the power system evolution. The inputs include power demand projections, current and potential Non-RE and RE generation capacity, Cost projections and emission capacity factors while outputs expected delivered includes the policy recommendations, least cost generation mix, total system cost and carbon emission levels derived from the power system based on the modelled possible future scenarios as shown in figure 2 the schematic diagram of the methodology.

Three Scenarios are modelled and run from 2020-2050 i.e. the Reference scenario and RE penetration access level scenarios. It should be noted that the outcome of the reference case scenario should not be regarded as the most likely path for the future electricity system, but rather as a baseline and benchmark based on the input variable assumptions and projections that distinguish it from the prevalent business as usual scenario. The remaining scenarios are created in order to address the study hypothesis stated in the introduction.

3.2.1 Reference Scenario

This refers to the base case scenario which is associated with regional master plan and national least cost development plans (EAPP, 2014) (Ministry of Energy and Petroleum, 2016) projections on economic and generation capacity that follow the past projected trends and development of the electricity generation technology. The demand projections considered for this research study are the sent out demand (demand prior losses) as opposed to the final demand since the model optimizes supply directly. To capture key elements of electricity demand patterns, the years are labeled as load profiles representing distinct seasons and hours of the day. After that, the year is divided into three seasons: January-April, May-August, and September-December. Each season is divided into ten blocks each day (with "Peak" at 8:00pm), resulting in 30 time slices every year with hours adjusted to East African Time Zone (EAT). The load profile information came from the IRENA MapRE project (IRENA, 2015).The cost assumptions adapted under this scenario includes 10% discount rate applied to all costs alongside the past and future estimated weighted average capital expenditure (CAPEX) derived from the cost in the master plan (EAPP, 2014). An additional 2% of the total cost is assumed as the infrastructure and transmission expenses to the grid connection. Hydropower and Geothermal are the most capital intensive among the committed and planned projects accounting for 4000USD/Kwh and 3000 USD/Kwh respectively (EAPP, 2014). For Non RE the generation costs are assumed to be tied with the commodity fuel prices they utilize whereby projected prices in (EAPP, 2014) are adapted whereby with relatively stable capital expenditure (CAPEX), the fuel costs are increasing by 5.5% annually. The variable operation and maintenance (VOM) which don't include fuel costs; Hydro power is assumed to be USD 3.3/MWh, Biomass USD 3.74/MWh and Solar USD 0.2/MWh according to (EAPP, 2014).The specific technological emission factors according to the (IPCC, 2018) are incorporated in the scenario modelled.

This is a scenario which seeks to show the energy systems case as it is and its evolution without constraints or targets imposed on the penetration of renewable and emission levels. It serves as the basis for the other alternative scenarios developed. It depicts the generation capacity, total system cost and derived system CO_2 emissions implications of the electricity generation mix to 2050 based on the model cost-optimization methodology and input assumptions discussed which is unique from the common Business As Usual scenario which doesn't endogenously consider the investment cost options. The scenario based on the assumptions the RE penetration level accounts for 75% and 55% for Kenya and Rwanda respectively by 2050.

3.2.2 Renewable Energy high Scenario (RE high)

This scenario is modelled in the study to investigate the outcome of a more ambitious utilization of renewable energy in the generation of electricity. It examines the additional investment required to scale up the implementation of renewable energy sources. o account up to 100% share of the generation by 2050 to comply with the global SDG 7 and SDG 13 goals and the Paris climate agreement (Teske et al., 2019) relative to reference scenario by 2050.

Under this scenario, all input assumptions adapted in the reference scenario are relevant with improvement under the generation potential capacity of RE where apart from existing and committed plants, candidate and generic capacity factors will also be considered based on data from (IRENA, 2003). In this regard, Site-specific projects that are still being considered as investment alternatives are tied to the earliest online year, and additional capacities will be modified based on data from the (IRENA, 2021).

These potential capacities will be endogenously deployed by model depending on demand, cost and emission factor assumptions as outlined in the reference scenario. However, under this scenario its assumed that the Solar and Wind levelized cost will be declining at 6% per annum according to the latest RE costs report (IRENA, 2013) while other fuel and O&M costs assumptions follows from the reference scenario. Lastly the calculation of CO_2 emission will be based on specific technology emission factors as per the current data from (IPCC, 2018) .

3.2.3 Renewable Energy Low Scenario (RE low)

The alternative scenario of a limiting RE penetration share in the power system to 50% is also modelled to show the implication of low share of RE in the electricity generation. This scenario represents a situation where there is an inability to implement RE projects due to other factors other than cost related factors which may include political and social factors. The restrictions limits RE penetration to 25% in 2020, 35% in 2030 and 50% in 2050 on the overall production of electricity in the two countries under study.

The demand projections considered for this scenario is the sent out demand as per (EAPP, 2014) as opposed to the final demand. In this regard, years are calibrated as load profiles to capture essential aspects of electricity consumption patterns throughout seasons and hours of the day. After that, the year is divided into three seasons: January-April, May-August, and September-December. Each season is divided into 10 blocks per day (with "Peak" at 8:00 p.m.); resulting in 30 time slices per year, with load profile data taken from the IRENA MapRE project. (IRENA, 2015).

The CAPEX costs assumptions follows from reference scenario while variable operation and maintenance (VOM) include fuel costs; while investment overnight costs of Hydro power is assumed to be USD 3.3/MWh, Biomass USD 3.74/MWh and Solar USD 0.2/MWh according to (EAPP, 2014) to calculate the overall system cost and levelized cost characteristics. The specific technological emission factors according to the (IPCC, 2018) are incorporated in to calculate the derived CO_2 from the scenario endogenously.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.0 Introduction

This section discusses in-depth modelled scenario outcomes and discussion of the insights from the results showing the implications of Renewable energy electricity generation replacing conventional energy sources. The results are geared towards answering each of the three study objectives i.e. Renewable and Nonrenewable energy generation capacity mix, the power system derived carbon dioxide emissions and the system costs implications compared across scenarios modelled for 2020 - 2050.

4.1 Presentation of Results

Table 3 Summary of Electricity generation mix, Costs and CO_2 Emission levels across scenarios

	REF		RE LOW		RE HIGH	
	KE	RW	KE	RW	KE	RW
RE electricity share in 2050 (%)	62.7	54.2	50.2	35.1	89.5	67.5
Non-RE Power Share in 2040 (%)	37.3	45.8	49.8	44.9	11.5	32.5
CO_2 Emissions (Mt per capita)	0.350	0.082	0.416	0.095	0.282	0.032
System Levelized electricity Costs (USD/Mwh)	9.81	10.15	9.51	9.83	10.17	10.73
Overall system costs (million $)	4487	2430	4305	2135	4667	2660
Total levelized CO_2 Abatement costs ($/ton)	23.5	18.3	-20.2	-25.7	55.9	66.3

From table 3 above, the summary results indicates that for the reference scenario, the RE power production share in 2040 will be 62.7% and 54.2% while Non-RE share will be 37.3% and 45.8% in Kenya and Rwanda respectively. Under the low scenario, the RE power production share will be 50.2% and 35.1% with Non-RE share of 49.8% and 44.9% in Kenya and Rwanda respectively. While the high scenario depicts RE power production share to be 89.5% and 67.5% with Non-RE share of 11.5% and 32.5% for Kenya and Rwanda respectively.

In terms of CO_2 emissions from the power system under this scenario, study results show that the emission level under the reference scenario will be 0.35mt per capita and 0.082 mt per capita for Kenya and Rwanda respectively. On the other hand, 0.416 and 0.095 Mt per capita emission level will be depicted under low scenario in Kenya and Rwanda respectively. The high scenario will be associated with 0.282 and 0.032 Mt per capita emission level in Kenya and Rwanda respectively in 2040.

Further the table shows the system levelized cost of generation needed in the three scenarios. The reference scenario will be associated with 9.81 and 10.15 (USD/Mwh) in Kenya and Rwanda respectively. In the low and high scenarios, 9.5 and 10.17 (USD/Mwh) will be needed in Kenya while 9.83 and 10.73 (USD/Mwh) will be required in Rwanda respectively. On the other hand the overall system costs under the reference scenario will be associated with $4487 and $2430 million for Kenya and Rwanda respectively. While the preceding scenario results for low and high scenario depicts $4305 and $4667 million for Kenya and $2135 and $2660 million needed in Rwanda respectively.

Additionally the scenario results show the cost of achieving CO_2 emission reductions, the levelized CO_2 abatement costs. Whereby under the reference scenario, 23.5and 18.3 $/ton will be required in Kenya and Rwanda respectively. The low scenario shows that -20.2 and -25.7 $/ton will be required to abate the CO_2 emissions in Kenya and Rwanda. Contrastly, under the RE high scenario the abatement costs required will be 55.9 and 66.3 $/ton in Kenya and Rwanda respectively.

4.1.1 Electricity Generation

Figure 3 below shows the power generation capacity mix and the technological share for the studied area for the period 2020 being the base year of the study. The RE energy sources grew in both cases relative to last few years where it account for 75% and 55% in Kenya and Rwanda respectively while Non RE account for 25% and 45% respectively. In Kenya the technology mix is composed of 11% wind, 31% Geothermal, 14% large hydro power, 3% small hydro power, 3% solar PV and 25% fossil fuel while Rwanda will be composed of 5% solar, 61% hydropower, 8% natural gas and 22% peat power to ensure that demand is met in totality.

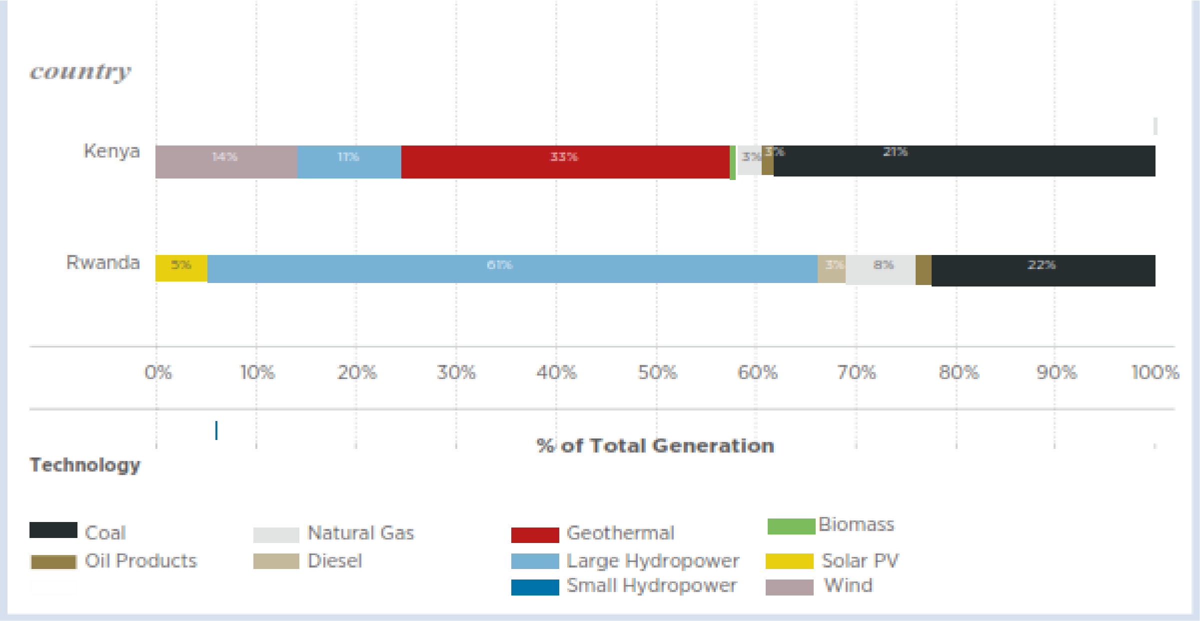


Figure 3 Electricity Generation capacities (2020)

However, figure 4 and 5 shows the comparison results of the possible generation technology mix across the scenarios modelled in Kenya and Rwanda respectively. Under RE high scenario, oil will be generating 200MW , small hydro 300MW, Wind power 500MW, Geothermal 1200MW, Biomass 300MW, large Hydro 600MW while Solar will be generating 650MW while RE low scenario, Oil thermal generation will be 700MW, small hydro 200MW, wind power 260MW, Geothermal energy 890MW,Biomass 250 MW, large Hydro power 550 MW and Solar 245MW in Kenya.

On the other hand in Rwanda power technology mix under the RE high scenario, the country's energy system will be composed of 45MW Oil thermal, 15MW peat to power, 65MW small Hydro power, 75 Mw large Hydro power, 63MW biomass and 103 MW solar. While under RE low scenario, the system generation will be composed of 65 MW Oil thermal, 25 MW peat to power, 55MW small Hydro power, 65 Mw large Hydro Power, 33MW biomass and 53 MW solar as shown in figure 5 below.

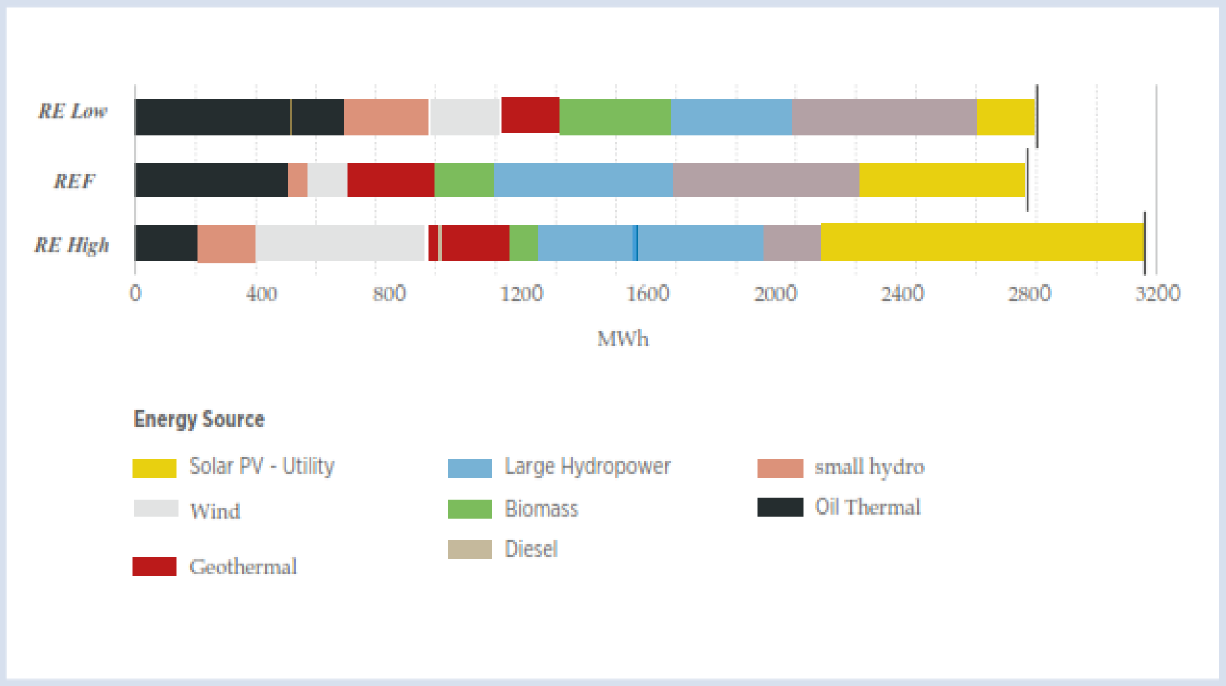


Figure 4 Electricity generation across Scenarios (Kenya)

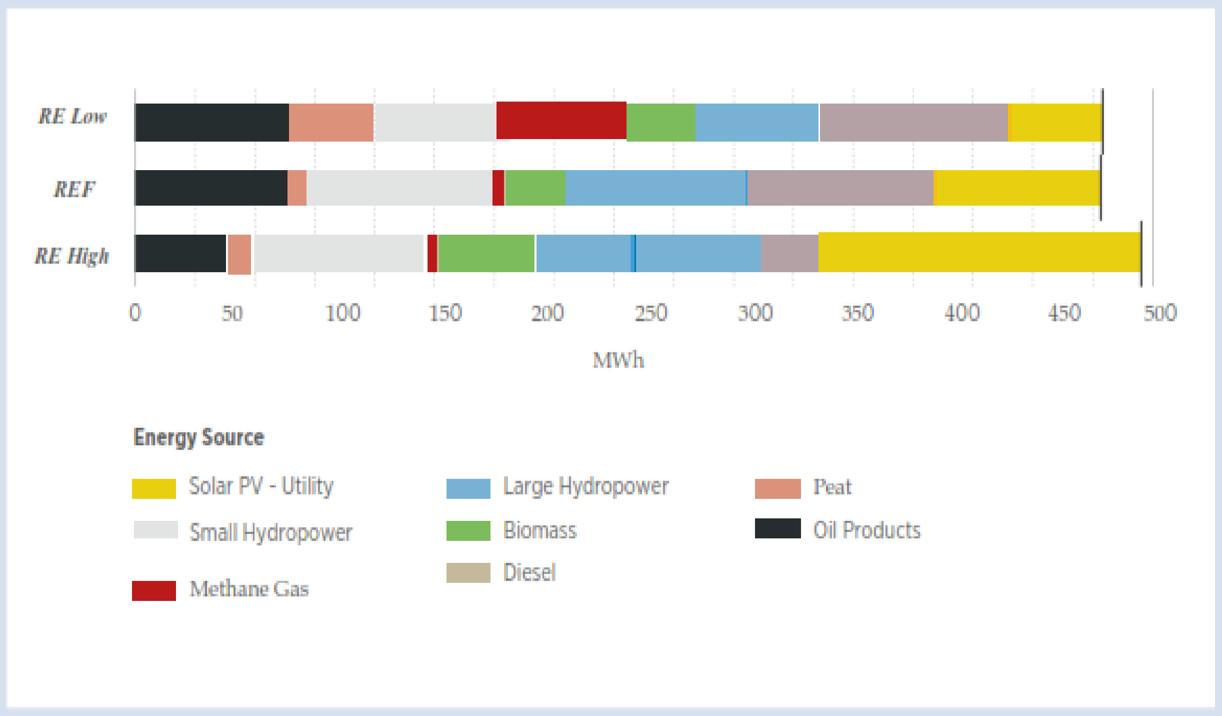


Figure 5 Electricity generation across the scenarios (Rwanda)

Finally, results in figure 6 show potential hourly generation profiles and how the generations mix will evolve as per the demand and patterns of production of different technologies under RE high scenario. The simulated results show hourly generation of the case study areas in 2020, 2030 and 2050. The results show that under the RE high scenario Renewable energy sources like Solar Pv, Wind and Geothermal are likely to displace conventional energy in energy generation throughout the day while meeting the projected demand in tandem. In Kenya Geothermal, Solar and Wind meets the average demand of 1000mw , 1500 MW and 2200MW during the day in 2020, 2030 and 2050 respectively .While in Rwanda average demand of 75MW, 97 MW and 120MW during the day in 2020, 2030 and 2050 respectively will be majorly catered for by Solar and Hydropower sources.

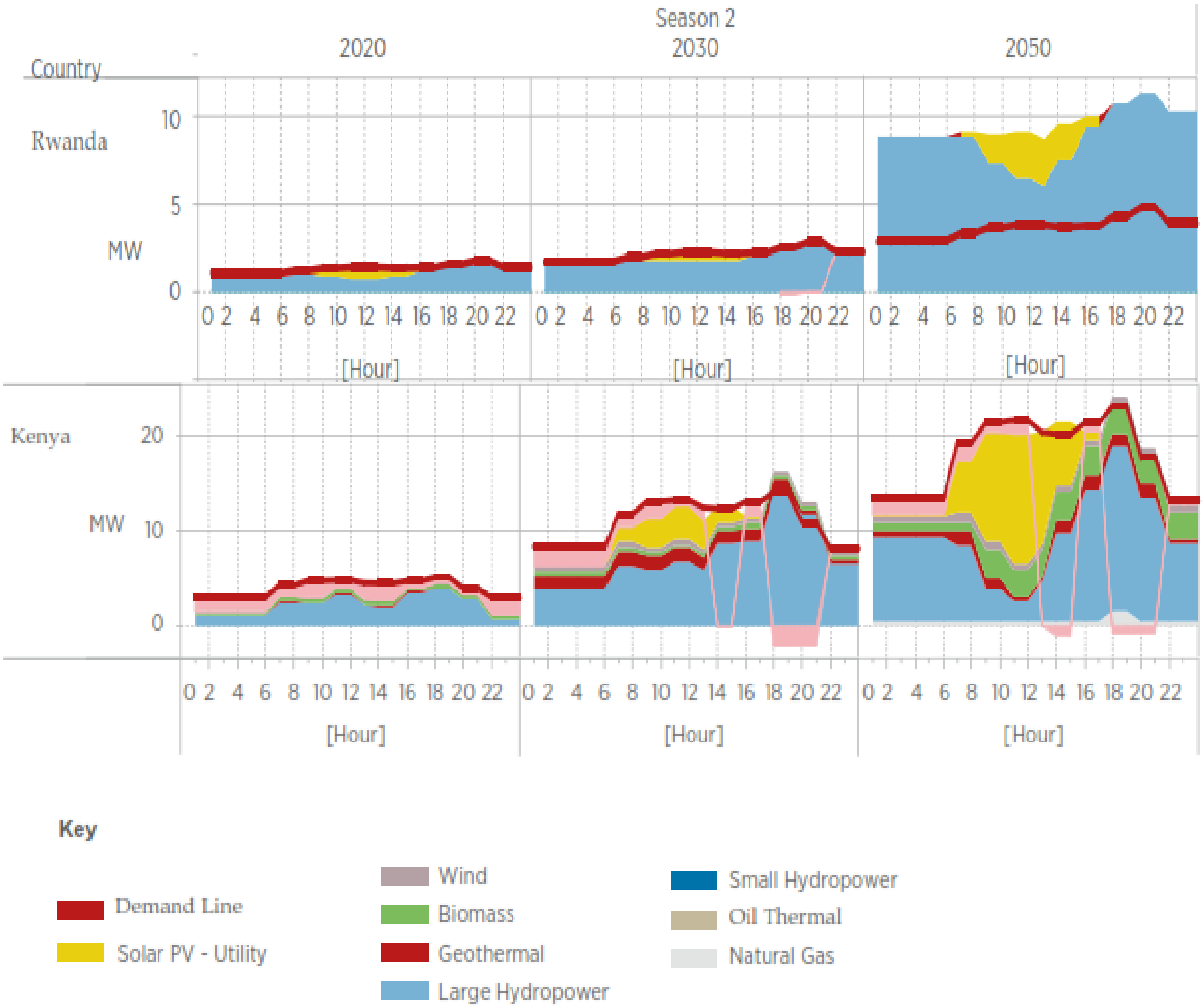


Figure 6 The hourly generation under RE high scenario

4.1.2 Electricity Generation CO_2 Emissions

Figure 7 above shows the results on the CO_2 emission trend in Rwanda over the scenarios modelled. Under the reference scenario, the CO_2 emissions from the Rwanda power system will be 0.075 mt in 2020 then will rise to 0.08mt at around 2026 and slightly decline in 2050 to 0.072mt in 2050. While under the RE high scenario the CO_2 emissions are depicted to be 0.072mt in 2026 and 0.045 mt by 2050. Similarly under the RE low scenario the emissions are slightly higher at 0.078 in 2025 and 0.095 in 2050.

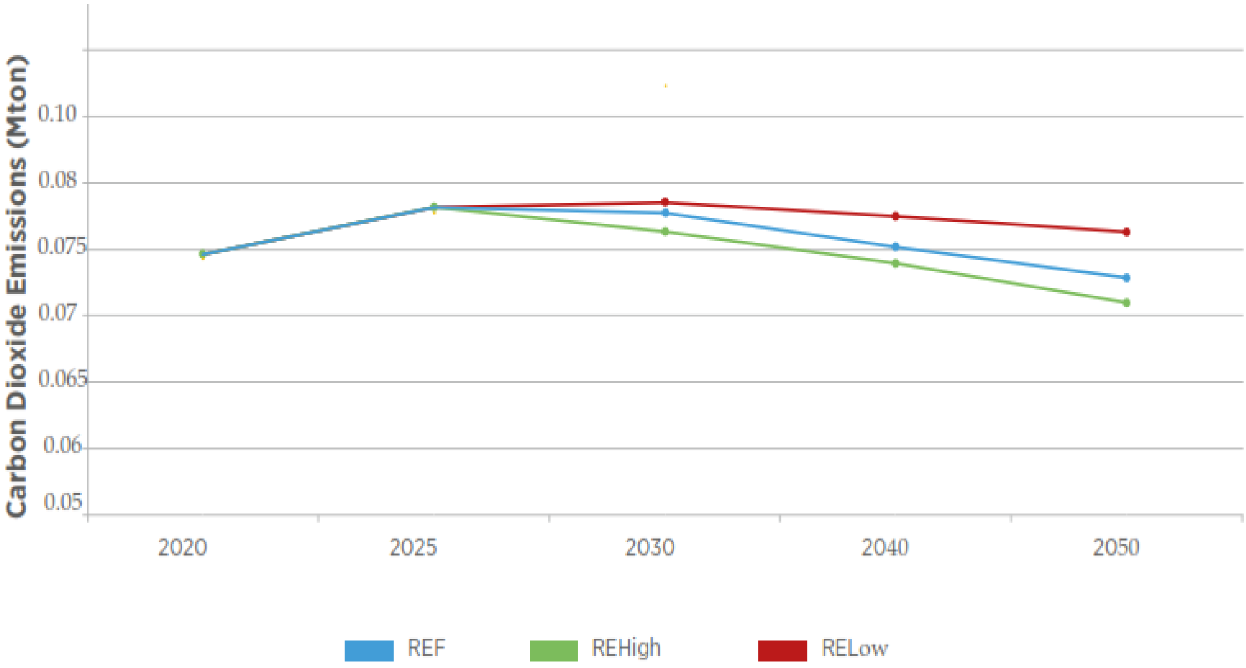


Figure 7 Rwanda CO_2 emissions Trend over the Scenarios

Figure 8 above shows the results on the CO_2 emission trend in Kenya over the scenarios modelled. Under the reference scenario, the CO_2 emissions from the Rwanda power system will be 0.40 mt in 2020 then will rise to 0.52 mt at around 2026 and slightly decline in 2050 to 0.48 mt in 2050. While under the RE high scenario the CO_2 emissions are depicted to be 0.32mt in 2026 and 0.25 mt by 2050. Similarly under the RE low scenario the emissions is slightly higher at 0.48mt in 2026 and 0.65mt in 2050.

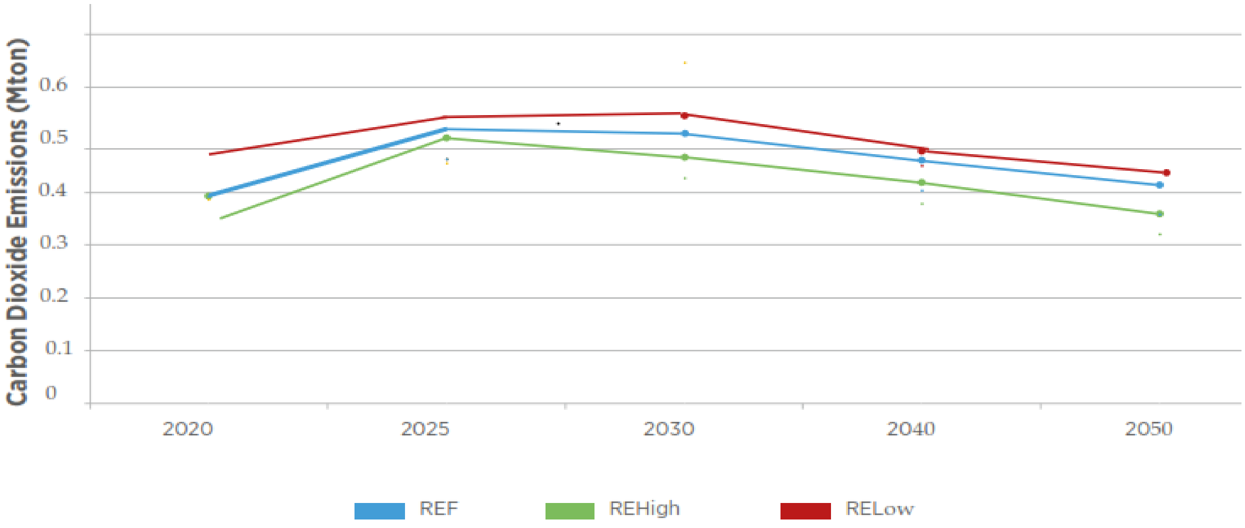


Figure 8 Kenya CO2 emissions Trend over the Scenarios

4.1.3 Cost of Electricity Generation

Table 3 shows the system levelized cost and overall system cost of electricity generation needed in the three scenarios. The reference scenario will be associated with 9.81 and 10.15 (USD/Mwh) in Kenya and Rwanda respectively. In the low and high scenarios, 9.5 and 10.17 (USD/Mwh) will be needed in Kenya while 9.83 and 10.73 (USD/Mwh) will be required in Rwanda respectively. On the other hand the overall system costs under the reference scenario will be associated with $4487 and $2430 million for Kenya and Rwanda respectively. While the preceding scenario results for low and high scenario depicts $4305 and $4667 million for Kenya and $2135 and $2660 million needed in Rwanda respectively.

However to understand how system cost change with RE penetration levels, figure 7 presents cumulatively both absolute and relative system cost terms as a function of RE penetration under low, Reference and High RE scenarios. The change in the total cost of the system cumulatively with changes in RE penetration is nonlinear where with Reference case; enforcing averagely 55% RE increases the cost by 0.25% relative to the optimal least cost solution of 75% RE penetration. However limiting RE penetration under RE low scenario, to 35% penetration it increases the total system cost by 5.8% relative to the optimal solution. Finally, increasing RE penetration to 99% leads to an increase of 14% relative to the reference least cost solution under this scenario as shown in figure 7 below.

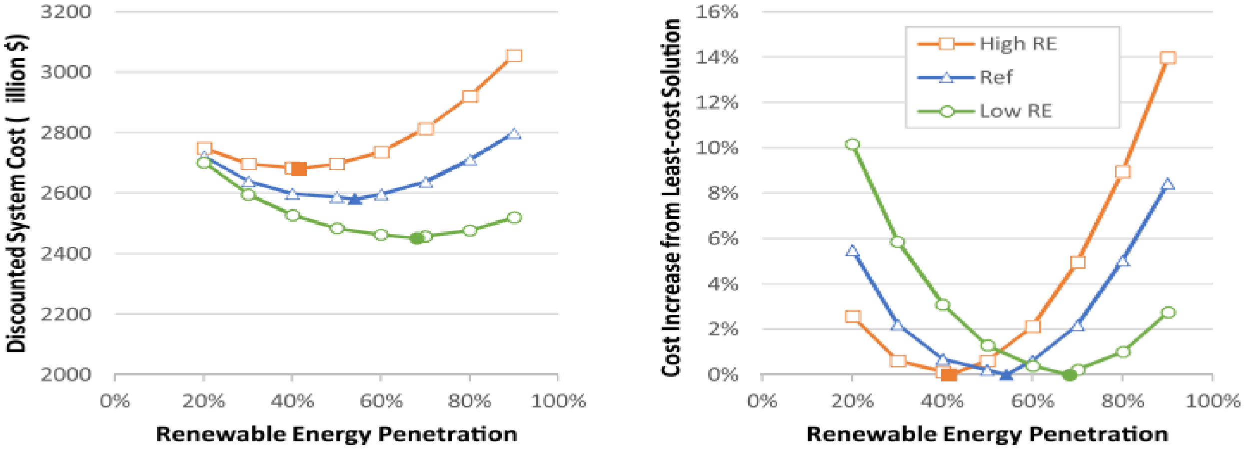


Figure 9 The effect of Renewable Energy penetration on System Costs

NB: Dotted point shows the least cost point in each scenario

The results show that in both cases the increase in RE penetration leads to decline in CO_2 emissions but independent on technology cost assumed. However, Figure 9 compares the costs of achieving those emission reductions using the levelized cost of CO_2 abatement using 10% discount rate. The results shows that the levelized cost of CO_2 abatement for RE penetration that is lower than the optimal least cost solution in each scenario are lower than 0 (negative) while scenarios with RE penetration higher than least cost solution results in a positive as at 90% RE penetration the abatement cost is $18-$58/ton.

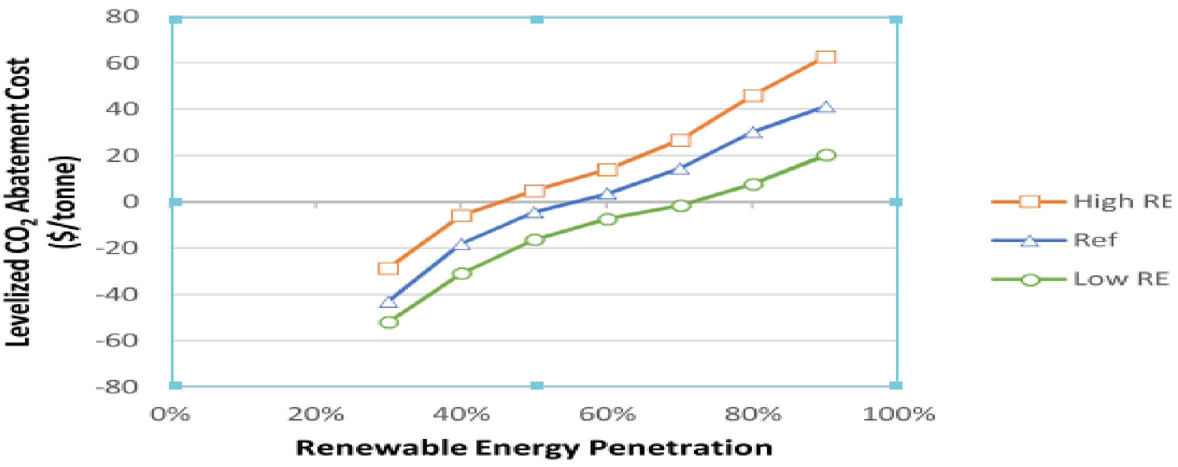


Figure 10 Levelized CO_2 abatement cost between scenarios.

4.2 DISCUSSION

In this study capacity expansion scenario analysis was used to compare implications of RE on the electricity generation and potential capacity, the electricity generation cost and the derived CO_2 emission from the system. A desirable scenario of RE high and alternative RE low scenario were taken and compared with a reference scenario without any further legal institutional policy restrictions attached to RE apart based on the recent regional master plan and least cost development plan (EAPP, 2014; Ministry of Energy and Petroleum, 2016). The study results were geared to answer each of the three specific objectives of the research as follows:-

From the results in table 4 above its evident that unless there will be re-adjustment of the master plans and country’s least cost development plans the current generation capacity will still use at average 35% fossil fuel and averagely 65% RE in power generation to meet the demand- supply gap by 2050. However the study results also reveals that the region has a vast potential of RE in terms of Solar PV, Geothermal, Biomass and wind energy which can be tapped to the grid at large scale leading to a flexible electricity system since it can cost effectively complement the most abundant RE (hydro power) in 2050.

In Rwanda the potential to generate electricity economically with local resources including, hydropower, peat, natural gas methane and geothermal energy has however, been estimated to total around 1,613 MW. Thus the country is therefore, utilizing < 10% of its local electricity generation potential while incurring a large foreign outflow. Similarly Kenya has large potential in Geothermal and Wind estimated at 10GW and 4000Mw that is just 8% utilized while still dispatching non-conventional sources and spends on imports. The study results is consistent with the findings by (Chambile et al., 2018; Ministry of Energy and Petroleum, 2016; Ouedraogo, 2017b) however these studies did not capture the magnitude of the potential capacity.

To meet the projected tripling demand at least cost and low CO_2 emissions level by 2050 as required by the global SDGs, the study results finds plausible to invest in Renewable energy technologies under the RE high scenario whereby the CO_2 emissions will be reduced by over 95% relative to current emission level under the reference scenario. The CO_2 emission results are compared over the Reference and RE low scenario results whose emission findings are averagely 40% reduction and 53%

increase of CO_2 emissions respectively. Indeed the model outputs indicate that RE generation current and potential capacity has a negative impact on both cost and CO_2 emission from the system while Non RE capacity and potential has a In the long run, this will have a positive impact on CO_2 emissions in East Africa. This implies that with relevant legal and institutional RE policy, the region can effectively reduce its electrical energy generation emissions by over 90% which will be falling within the (IPCC, 2018) and SDG 7 and SDG 13 requirements by 2050. This study findings is consistent with findings of (Chambile et al., 2020; Mabea, 2020; Uhorakeye, 2016) on the effect of RE on the CO_2 emission levels globally and regionally respectively. Therefore, the study identifies some of the theories that could answer the underlying research hypothesis. For example what could be explaining RE negative effect on CO_2 emission in East Africa? Or what could be explaining Non-RE positive effect on CO_2 emission in East Africa?

The possible explanation for the positive effect under of Non-RE on CO_2 emission is related to fossil fuel being the primary and basic input in Agriculture and industry under RE_low scenario which increase the electricity demand and consequently increases the CO_2 emissions considering the high emission factor compared to the RE (Chambile et al., 2020; Koengkan & Fuinhas, 2020; Vural, 2020). On the other hand the possible explanation for Renewable energy transition proxied by RE of reducing CO_2 emission in East Africa is definitely related to the technological efficiency which produces fewer amounts of CO_2 emissions (depicted by low emission factor) as well as increasing pressure to invest on the green energy (IPCC, 2018; Koengkan & Fuinhas, 2020; Paramati et al., 2017; Silva et al., 2012)

The generation cost implication results depicted in the previous section reveals that due to the geographical location of RE sources and the proximity to the load centers, there is a possibility of cost-effective and competitiveness of RE over Non-RE in a nonlinear relationship. Specifically, this suggests that a little increase or decrease in RE penetration has a negligible effect on system costs. while large increase/declines results to large changes this is seen under 100% RE electricity generation scenario, deploying Solar and Wind at large scale to complement other non-variable RE like Geothermal, Biomass and Hydro power the total levelized cost of electricity will be approximately 14.5% system cost increase compared to the reference scenario and low scenarios resulting to 0.25% and 5.8% increase in system cost respectively by 2050.Thus it’s needless to say that because of non-linear curve relationship, with rapid economic development and the improving trend in access to electricity, the cost of using and deploying a given RE penetration level is largely dependent on the ideal cost solution's RE penetration level. of increased transmission of power generated from areas of high potential.

The estimated levelized cost of electricity from Solar and Wind will be as low as US 0.10 and 0.16 per Kwh in 2050 following the learning cost curve adopted of which it will play a critical role in reducing the total levelized costs under RE generation scenario. The study findings under this objective is consistent with findings of (Adeyeye et al., 2021; Boudjella & d'Amour, 2018; IRENA, 2015). However, the results finding also contradicts outcomes of some other studies which report otherwise like (Dogan & Seker, 2016; Kichonge et al., 2015; Vural, 2020). Therefore the results in our study also appoint the possible theories that could answer the underlying research hypothesis. For example what could be explaining RE negative effect on cost in East African countries? Or what could be explaining Non-RE positive effect on cost in East Africa countries?

In the case of the RE negative effect on the cost of electricity generation, it can be explained by the current decline trajectory of individual RE technology LCOE due to technological and efficiency improvements through the learning theory coupled with very low VOM, O&M costs and zero fuel costs making them competitive compared to fossil fuel (IRENA, 2021; Ouedraogo, 2017b; Saadi et al., 2015; Yue et al., 2020). While the possible explanation of the positive impact on the electricity generation cost is related to the fact that fossil fuel involve a high capital costs coupled with O&M and fuel costs which are proxied by commodity prices that are ever rising due to inflation and other factors according to (Borenstein, 2012; Chakamera & Alagidede, 2018; Ouedraogo, 2017b).

Given that from the results emission reductions is associated with increase RE deployment concurring with previous studies (Chambile et al., 2020; Cole et al., 2021), the value of CO_2 emission reduction is compared to the cost of achieving the reduction. The system cost and CO_2 emission was translated in the SPLAT model into levelized CO_2 abatement cost applying 10% discount rate. This cost is derived by dividing the difference in system cost by the variance in CO_2 emissions (all calculated over the model horizon) between successive RE penetration scenarios. The results shows that the levelized abatement cost for the RE low scenarios with small RE penetration level have negative abatement costs while Scenarios of high RE penetration have positive levelized CO_2 abatement costs.

Specifically, at over 90% RE penetration under the high scenario abatement costs ranges between \$18-\$58/ton while in contrary RE penetrations of less than 20% translates into -\$20 to -\$45/ ton. This basically means that costs are incurred in order to minimize emissions while opportunity cost is seen in a scenario where emissions are not reduced.

In a nut shell, the results presented in the previous section, highlights that RE consumption have a positive significant effect on generation cost and negative significant effect on CO_2 emissions in developing economies in East Africa. Thus, the results confirms and endorses findings by (Chambile et al., 2020; Kichonge et al., 2015) that revealed that increase in RE leads to reduction in CO_2 emissions. In addition, the findings also imperatively verify the positive impact of Non-RE on CO_2 emissions as depicted by (Al-Mulali et al., 2014; Apergis & Payne, 2011; Hanif et al., 2019) that due to inefficient technologies used in most developing economies, there is massive consumption of Non-RE which results to excessive generation and emission of CO_2 into the atmosphere. However, while findings are in line with some similar studies, it also contradicts and criticizes other study findings. For example, the research findings found by (Apergis & Payne, 2014; Paramati et al., 2017) presents a positive short run correlation between RE and CO_2 emission with a long run significant positive implications of Non-RE and CO_2 emission. Further, the findings contributes to the literature by showing the relationship between RE and the system generation cost which is significantly non-linear showing that the effect depends on the magnitude of RE penetration while showing the trade-off between CO_2 emission saving and the system cost. Thus it’s evident that reducing the CO_2 emission and GHG in general will be a great challenge that will require stronger RE investment policies than are currently argued by the policy makers.

CHAPTER 5: CONCLUSIONS AND POLICY RECCOMMENDATIONS

5.0 Introduction

This chapter seeks to highlight the general conclusion of the study, provide research contribution to the literature as well as suggesting some policy interventions and areas of future research on the topic.

5.1 Conclusions

The study presents Renewable energy scenarios for East Africa on a country level. The scenarios describes the economic and environmental implications of using various types of technologies in power generation and thus providing a way the governments should invest cost effectively in order to cover the expected demand at the same time combating climate change by meeting the nationally determined contribution (NDC). This study therefore examines what will be generation options in the region through a scenario capacity expansion modelling determining its associated implications on investment cost needs and carbon dioxide emissions derived from the system. The scenarios provide plausible futures and therefore the results and conclusion should be viewed from a descriptive point rather than prescriptive.

The key assumptions adopted for the model calibrated which influenced the technology deployment mix over time includes those relating to fossil fuel prices, RE cost developments, RE resources potentials and fossil fuel reserve capacities. The results elude that penetration and deployment of RE technologies particularly Solar PV, Hydro power, Wind and Geothermal technologies will have a nonlinear relationship to the total system costs. Particularly, increasing/decreasing RE capacity from current by ±10% shows increases the system costs by 1%-2% in 2050. While changing RE penetration level by ±20% will increase the system costs by averagely 13%-14% when compared to the optimal cost solution benchmark. Increasing RE penetration beyond this reference level leads to higher system costs but with greater reductions in CO_2 emissions (almost zero). Comparing emissions and system costs yields the levelized CO_2 abatement cost which is incremental to RE deployment and declines as RE deployment is curtailed.

5.2 Policy Recommendations

The study did not incorporate the aspect of electricity trade and storage implication which can be area of interest in the future studies. Thus, the model calibrated under this study could be further improved and enhanced to capture but not limited to the following important dynamic parameters not captured in this study :-

1. Consider trans-border electricity trade of RE.
2. Consider hydropower and Solar Pv with storage capacity
3. Include estimation of water losses in hydropower and system losses during transmission.
4. Expand electricity sector to include off grid and decentralized systems.

From the policy point of view, in order to realize the almost zero carbon dioxide emission in a cost effective and economically sound manner, the study recommends strict and stringent implementation of strategies to improve RE generation investments as well as transmission and distribution. For example regarding high increase in cost of generation as a result of deploying high RE, the developing countries governments should engage international bodies and develop agreements to exchange cost-effective technologies to promote RE sources through providing subsidies based on the amount of CO_2 abatement levelized costs so as to increase RE competitiveness.

Additionally, should promote solar energy, encourage Renewable energy Research and Development, remove barriers to renewable energy investment by developing legal policy and institutions to support renewable-based rural electrification. Further, RE deployment plan should be done based on the current state of electricity and taking into account the resource potential and cost developments precision being centered around a system that is at least near the reference optimum level as an opportunity to leapfrog to the renewables at cost minimization perspective.

REFERENCES

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO2 emissions: Evidence from Sub-Saharan Africa economies. *Utilities Policy*, *41*, 85–94. https://doi.org/10.1016/j.jup.2016.06.009

Adeyeye, K. A., Ijumba, N., & Colton, J. S. (2021). *Low Wind Speed Areas*. 1–21.

Akinyemi, O., Efobi, U., Osabuohien, E., & Alege, P. (2019). Regional Integration and Energy Sustainability in Africa: Exploring the Challenges and Prospects for ECOWAS. *African Development Review*, *31*(4), 517–528. https://doi.org/10.1111/1467-8268.12406

Al-Mulali, U., Fereidouni, H. G., & Lee, J. Y. M. (2014). Electricity consumption from renewable and non-renewable sources and economic growth: Evidence from Latin American countries. *Renewable and Sustainable Energy Reviews*, *30*, 290–298. https://doi.org/10.1016/j.rser.2013.10.006

Amigues, J. P., Kama, A. A. Le, & Moreaux, M. (2015). Equilibrium transitions from non-renewable energy to renewable energy under capacity constraints. *Journal of Economic Dynamics and Control*, *55*(266992), 89–112. https://doi.org/10.1016/j.jedc.2015.04.001

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy*, *38*(1), 656–660. https://doi.org/10.1016/j.enpol.2009.09.002

Apergis, N., & Payne, J. E. (2011). Renewable and non-renewable electricity consumption-growth nexus: Evidence from emerging market economies. *Applied Energy*, *88*(12), 5226–5230. https://doi.org/10.1016/j.apenergy.2011.06.041

Apergis, N., & Payne, J. E. (2014). Renewable energy, output, CO2 emissions, and fossil fuel prices in Central America: Evidence from a nonlinear panel smooth transition vector error correction model. *Energy Economics*, *42*, 226–232. https://doi.org/10.1016/j.eneco.2014.01.003

Aydoğan, B., & Vardar, G. (2020). Evaluating the role of renewable energy, economic growth and agriculture on CO2 emission in E7 countries. *International Journal of Sustainable Energy*, *39*(4), 335–348. https://doi.org/10.1080/14786451.2019.1686380

Azhar Khan, M., Zahir Khan, M., Zaman, K., & Naz, L. (2014). Global estimates of energy consumption and greenhouse gas emissions. *Renewable and Sustainable Energy Reviews*, *29*, 336–344. https://doi.org/10.1016/j.rser.2013.08.091

Ben Jebli, M., Ben Youssef, S., & Ozturk, I. (2015). The Role of Renewable Energy Consumption and Trade: Environmental Kuznets Curve Analysis for Sub-Saharan Africa Countries. *African Development Review*, *27*(3), 288–300. https://doi.org/10.1111/1467-8268.12147

Bhattacharyya, S. C. (2019). Energy economics: Concepts, issues, markets and governance, 2nd ed. 2019. In *Energy Economics: Concepts, Issues, Markets and Governance, 2nd ed. 2019*. https://doi.org/10.1007/978-1-4471-7468-4

Borenstein, S. (2012). The private and public economics of renewable electricity generation. *Journal of Economic Perspectives*, *26*(1), 67–92. https://doi.org/10.1257/jep.26.1.67

Boudjella, A., & d'Amour, M. J. (2018). East Africa Region Energy Projection with the Carbon Emissions for Conventional Energy. *Computational Water, Energy, and Environmental Engineering*, *07*(02), 69–79. https://doi.org/10.4236/cweee.2018.72004

Brown, I. (2015). *Bookstore - The Great Transition: Shifting from Fossil Fuels to Solar and Wind Energy | EPI*. http://www.earth-policy.org/books/tgt

Carvallo, J. P., Shaw, B. J., Avila, N. I., & Kammen, D. M. (2017). Sustainable Low-Carbon

Expansion for the Power Sector of an Emerging Economy: The Case of Kenya. *Environmental Science and Technology*, *51*(17), 10232–10242. https://doi.org/10.1021/acs.est.7b00345

Chakamera, C., & Alagidede, P. (2018). Electricity crisis and the effect of CO2 emissions on infrastructure-growth nexus in Sub Saharan Africa. *Renewable and Sustainable Energy Reviews*, *94*(July 2017), 945–958. https://doi.org/10.1016/j.rser.2018.06.062

Chambile, E., Ijumba, N., Mkandawire, B., & De Dieu Hakizimana, J. (2018). Impact of Electrical Power Systems on the Environment in Kenya, Rwanda and Tanzania. *2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018*, *Dc*, 885–889. https://doi.org/10.1109/PowerAfrica.2018.8521092

Chambile, E., Ijumba, N., Mkandawire, B., & De DIeu Hakizimana, J. (2020). Grid Electricity Generation Systems Comparisons Using the Life Cycle Carbon Emission Inventory. *2020 IEEE PES/IAS PowerAfrica, PowerAfrica 2020*, 2–6. https://doi.org/10.1109/PowerAfrica49420.2020.9219876

Chang, M., Thellufsen, J. Z., Zakeri, B., Pickering, B., Pfenninger, S., Lund, H., & Østergaard, P. A. (2021). Trends in tools and approaches for modelling the energy transition. *Applied Energy*, *290*. https://doi.org/10.1016/j.apenergy.2021.116731

Chang, Y., Choi, Y., Kim, C. S., Miller, J. I., & Park, J. Y. (2021). Forecasting regional long-run energy demand: A functional coefficient panel approach. *Energy Economics*, *96*, 105117. https://doi.org/10.1016/j.eneco.2021.105117

Chen, J., Wang, P., Cui, L., Huang, S., & Song, M. (2018). Decomposition and decoupling analysis of CO2 emissions in OECD. *Applied Energy*, *231*(September), 937–950. https://doi.org/10.1016/j.apenergy.2018.09.179

Cole, W., Gates, N., & Mai, T. (2021). Exploring the cost implications of increased renewable energy for the U.S. power system. *Electricity Journal*, *34*(5), 106957. https://doi.org/10.1016/j.tej.2021.106957

De Klein, C. A. M., & Eckard, R. J. (2008). Targeted technologies for nitrous oxide abatement from animal agriculture. *Australian Journal of Experimental Agriculture*, *48*(1–2), 14–20. https://doi.org/10.1071/EA07217

Deichmann, U., Meisner, C., Murray, S., & Wheeler, D. (2011). The economics of renewable energy expansion in rural Sub-Saharan Africa. *Energy Policy*, *39*(1), 215–227. https://doi.org/10.1016/j.enpol.2010.09.034

Dogan, E., & Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Renewable Energy*, *94*(2016), 429–439. https://doi.org/10.1016/j.renene.2016.03.078

EAPP. (2014). *EAPP REGIONAL EXECUTIVE*. *December*.

Energy, W., & Special, O. (2018). *Africa energy outlook*. https://doi.org/10.1787/g2120ab250-en

Eom, J., Edmonds, J., Krey, V., Johnson, N., Longden, T., Luderer, G., Riahi, K., & Van Vuuren, D. P. (2015). The impact of near-term climate policy choices on technology and emission transition pathways. *Technological Forecasting and Social Change*, *90*(PA), 73–88. https://doi.org/10.1016/j.techfore.2013.09.017

EPA, U. (2019). *Overview of Greenhouse Gases*. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Fang, Y. (2011). Economic welfare impacts from renewable energy consumption: The China experience. *Renewable and Sustainable Energy Reviews*, *15*(9), 5120–5128. https://doi.org/10.1016/J.RSER.2011.07.044

GCP. (2020). *Global Carbon Project (GCP)*.

Guta, D., & Börner, J. (2017). Energy security, uncertainty and energy resource use options in Ethiopia: A sector modelling approach. *International Journal of Energy Sector Management*, *11*(1), 91–117. https://doi.org/10.1108/IJESM-04-2015-0005

Haegel, N. M., Margolis, R., Buonassisi, T., Feldman, D., Froitzheim, A., Garabedian, R., Green, M., Glunz, S., Henning, H. M., Holder, B., Kaizuka, I., Kroposki, B., Matsubara, K., Niki, S., Sakurai, K., Schindler, R. A., Tumas, W., Weber, E. R., Wilson, G., … Kurtz, S. (2017). Terawatt-scale photovoltaics: Trajectories and challenges. *Science*, *356*(6334), 141–143. https://doi.org/10.1126/science.aal1288

Hafner, M., Tagliapietra, S., Falchetta, G., & Occhiali, G. (2019). *Manfred Hafner Simone Tagliapietra Giacomo Falchetta Giovanni Occhiali*.

Hakizimana, J. de D. K., & Kim, H. T. (2016). Peat briquette as an alternative to cooking fuel: A techno-economic viability assessment in Rwanda. *Energy*, *102*, 453–464. https://doi.org/10.1016/j.energy.2016.02.073

Hakizimana, J. de D. K., Yoon, S. P., Kang, T. J., Kim, H. T., Jeon, Y. S., & Choi, Y. C. (2016). Potential for peat-to-power usage in Rwanda and associated implications. *Energy Strategy Reviews*, *13–14*, 222–235. https://doi.org/10.1016/j.esr.2016.04.001

Hanif, I., Aziz, B., & Chaudhry, I. S. (2019). Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia. *Renewable Energy*, *143*, 586–595. https://doi.org/10.1016/j.renene.2019.05.032

IAEA. (2017). *IAEA ANNUAL REPORT 2017 IAEA Annual Report 2017*.

IEA. (2018). World Energy Outlook 2018: Highlights. *International Energy Agency*, *1*, 1–661. https://www.oecd-ilibrary.org/energy/world-energy-outlook-2018/executive-summary_weo-2018-2-en

IEA. (2019a). *IEA: Africa energy outlook: A focus on energy prospects... - Google Scholar*. https://scholar.google.com/scholar_lookup?title=Africa Energy Outlook&author=IEA&publication_year=2014

IEA. (2019b). *IEA webstore. World Energy Outlook 2019*. https://webstore.iea.org/world-energy-outlook-2019

IPCC. (2013). *AR5 Climate Change 2013: The Physical Science Basis — IPCC*. https://www.ipcc.ch/report/ar5/wg1/

IPCC. (2018). Proposed outline of the special report in 2018 on the impacts of global warming of 1 . 5 ° C above pre-industrial levels and related global greenhouse gas emission pathways , in the context of strengthening the global response to the threat of climate cha. *Ipcc - Sr15*, *2*(October), 17–20. www.environmentalgraphiti.org

IPPC. (2018). 済無No Title No Title No Title. *Paper Knowledge . Toward a Media History of Documents*.

IRENA. (2003). *Estimating the Renewable Energy Potential in Africa: A GIS-based approach.https://www.irena.org/publications/2015/Mar/Africa-Power-Sector-Planning-and-Prospects-for-Renewable-Energy-synthesis-report*. *18*(2), 29–31.

IRENA. (2013). Renewable power generation costs in 2012: An Overview. *Irena*, 1–8.

IRENA. (2015). *Renewable Energy Zones for the Africa Clean Energy Corridor*. *October*.

IRENA. (2021). *Planning and Prospects for Renewable Power: Eastern and Southern Africa*. Publication forthcoming

IRENA, GIZ, & KfW. (2020). *The Renewable Energy Transition in Africa*.

https://www.giz.de/en/worldwide/85301.html

Jae, K., Lee, H., & Koo, Y. (2020). Research on local acceptance cost of renewable energy in South Korea : A case study of photovoltaic and wind power projects. *Energy Policy*, *144*(June), 111684. https://doi.org/10.1016/j.enpol.2020.111684

Jean De Dieu, U., Teke, A., & Ibrikci, T. (2016). Current Overview of Renewable Energy Resources in Rwanda. *Journal of Energy and Natural Resources*, *5*(6), 92–97. https://doi.org/10.11648/j.jenr.20160506.13

Kebreab, E., Clark, K., Wagner-Riddle, C., & France, J. (2006). Methane and nitrous oxide emissions from Canadian animal agriculture: A review. *Canadian Journal of Animal Science*, *86*(2), 135–158. https://doi.org/10.4141/a05-010

Kichonge, B., John, G. R., & Mkilaha, I. S. N. (2015). Modelling energy supply options for electricity generations in Tanzania. *Journal of Energy in Southern Africa*, *26*(3), 41–57. https://doi.org/10.17159/2413-3051/2015/v26i3a2128

Koengkan, M., & Fuinhas, J. A. (2020). Exploring the effect of the renewable energy transition on CO2 emissions of Latin American & Caribbean countries. *International Journal of Sustainable Energy*, *39*(6), 515–538. https://doi.org/10.1080/14786451.2020.1731511

KPLC. (2021). *Power Sector Documents | kplc.co.ke*. https://www.kplc.co.ke/content/item/51/power-sector-documents

Lin, B., & Jia, Z. (2019). Impacts of carbon price level in carbon emission trading market. *Applied Energy*, *239*(January 2018), 157–170. https://doi.org/10.1016/j.apenergy.2019.01.194

Mabea, G. A. (2020). Electricity market coupling and investment in renewable energy: East Africa Community power markets. *International Journal of Sustainable Energy*, *39*(4), 321–334. https://doi.org/10.1080/14786451.2019.1709461

Ministry of Energy and Petroleum. (2016). *Development of a Power Generation and Transmission Master Plan , Kenya*. *I*(October), 91.

Musonye, X. S., Davíðsd�ottir, B., Kristj�ansson, R., �Asgeirsson, E. I., & Stef�ansson, H. (2020). *Integrated energy systems ' modeling studies for sub-Saharan Africa : A scoping review Eyj o*. *128*(May).

Neuhoff, K., Diekmann, J., Kunz, F., Rüster, S., Schill, W. P., & Schwenen, S. (2016). A coordinated strategic reserve to safeguard the European energy transition. *Utilities Policy*, *41*, 252–263. https://doi.org/10.1016/j.jup.2016.02.002

Newbery, D. M. (2016). Towards a green energy economy? The EU Energy Union's transition to a low-carbon zero subsidy electricity system – Lessons from the UK's Electricity Market Reform. *Applied Energy*, *179*(2016), 1321–1330. https://doi.org/10.1016/j.apenergy.2016.01.046

Ouedraogo, N. S. (2017a). *Africa energy future_ Alternative scenarios and their implications for sustainable development strategies | Elsevier Enhanced Reader*. https://reader.elsevier.com/reader/sd/pii/S0301421517301684?token=E959BD63C1B9BBE30F307CCC45D763B5B782EECF480A9FD37AFCA8256E1FCFB7D6110A5602F788E8B674FA28077A1D6C&originRegion=eu-west-1&originCreation=20210518150902

Ouedraogo, N. S. (2017b). Africa energy future: Alternative scenarios and their implications for sustainable development strategies. *Energy Policy*, *106*, 457–471. https://doi.org/10.1016/j.enpol.2017.03.021

Pandey, R. (2002). Energy policy modelling: Agenda for developing countries. *Energy Policy*, *30*(2), 97–106. https://doi.org/10.1016/S0301-4215(01)00062-3

Paramati, S. R., Mo, D., & Gupta, R. (2017). The effects of stock market growth and renewable energy use on CO2 emissions: Evidence from G20 countries. *Energy Economics*, *66*, 360–371. https://doi.org/10.1016/j.eneco.2017.06.025

REG. (2020). *Facts & Figures Details*. https://www.reg.rw/facts-figures/facts-figures-details/facts/installed-generation-capacity-on-the-national-grid/

REN21. (2021). *Renewables in cities status report 2021_REN21*.

Renewable, I., & Agency, E. (2016). *Renewable capacity statistics 2016 Statistiques de capacité renouvelable 2016 Estadísticas de capacidad renovable 2016*.

Rwanda Energy Sector Review and Action Plan. (n.d.).

Saadi, N., Miketa, A., & Howells, M. (2015). African Clean Energy Corridor: Regional integration to promote renewable energy fueled growth. *Energy Research and Social Science*, *5*, 130–132. https://doi.org/10.1016/j.erss.2014.12.020

Schmidt, O., Hawkes, A., Gambhir, A., & Staffell, I. (2017). The future cost of electrical energy storage based on experience rates. *Nature Energy*, *2*(8), 1–8. https://doi.org/10.1038/nenergy.2017.110

Shahbaz, M., Solarin, S. A., Sbia, R., & Bibi, S. (2015). Does energy intensity contribute to CO2 emissions? A trivariate analysis in selected African countries. *Ecological Indicators*, *50*(64335), 215–224. https://doi.org/10.1016/j.ecolind.2014.11.007

Silva, S., Soares, I., & Pinho, C. (2012). The impact of renewable energy sources on economic growth and co 2 emissions - A svar approach. *European Research Studies Journal*, *15*(SPECIAL ISSUE), 133–144. https://doi.org/10.35808/ersj/374

Sovacool, B. K., Kester, J., de Rubens, G. Z., & Noel, L. (2018). Expert perceptions of low-carbon transitions: Investigating the challenges of electricity decarbonisation in the Nordic region. *Energy*, *148*, 1162–1172. https://doi.org/10.1016/J.ENERGY.2018.01.151

Spittler, N., Davidsdottir, B., Shafiei, E., & Diemer, A. (2021). Implications of renewable resource dynamics for energy system planning: The case of geothermal and hydropower in Kenya. *Energy Policy*, *150*(August 2020), 111985. https://doi.org/10.1016/j.enpol.2020.111985

Steffen, B. (2020). Estimating the cost of capital for renewable energy projects. *Energy Economics*, *88*, 104783. https://doi.org/10.1016/j.eneco.2020.104783

Takase, M., Kipkoech, R., & Essandoh, P. K. (2021). A comprehensive review of energy scenario and sustainable energy in Kenya. *Fuel Communications*, *7*, 100015. https://doi.org/10.1016/j.jfueco.2021.100015

Taliotis, C., Shivakumar, A., Ramos, E., Howells, M., Mentis, D., Sridharan, V., Broad, O., & Mofor, L. (2016). An indicative analysis of investment opportunities in the African electricity supply sector - Using TEMBA (The Electricity Model Base for Africa). *Energy for Sustainable Development*, *31*, 50–66. https://doi.org/10.1016/j.esd.2015.12.001

Teske, S., Pregger, T., Naegler, T., Simon, S., Pagenkopf, J., van den Adel, B., & Deniz, Ö. (2019). Energy Scenario Results. In S. Teske (Ed.), *Achieving the Paris Climate Agreement Goals: Global and Regional 100{\%} Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5{\textdegree}C and +2{\textdegree}C* (pp. 175–401). Springer International Publishing. https://doi.org/10.1007/978-3-030-05843-2_8

Uhorakeye, T. (2016). PhD Dissertation: Modelling electricity supply options for Rwanda in the face of climate change. *Europa-Universität Flensburg*, *December*, 12–16. https://www.zhb-flensburg.de/fileadmin/content/spezial-einrichtungen/zhb/dokumente/dissertationen/uhorakeye/dissertation-uhorakeye.pdf

UNIDO. (2016). East African Community (EAC) Renewable energy and energy efficiency status report. *Ren21*. http://www.ren21.net/eac-renewable-energy-status-report-press-page/

US EPA, O. (2020). *Fluorinated Greenhouse Gas Emissions and Supplies Reported to the GHGRP*. https://www.epa.gov/ghgreporting/fluorinated-greenhouse-gas-emissions-and-supplies-reported-ghgrp

Verbruggen, A., Fischedick, M., Moomaw, W., Weir, T., Nadaï, A., Nilsson, L. J., Nyboer, J., & Sathaye, J. (2010). Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy*, *38*(2), 850–861. https://doi.org/10.1016/j.enpol.2009.10.036

Verzijlbergh, R. A., De Vries, L. J., Dijkema, G. P. J., & Herder, P. M. (2017). Institutional challenges caused by the integration of renewable energy sources in the European electricity sector. *Renewable and Sustainable Energy Reviews*, *75*(November 2015), 660–667. https://doi.org/10.1016/j.rser.2016.11.039

Vural, G. (2020). Renewable and non-renewable energy-growth nexus: A panel data application for the selected Sub-Saharan African countries. *Resources Policy*, *65*(December 2019), 101568. https://doi.org/10.1016/j.resourpol.2019.101568

WEC. (2019). *World Energy Issues Monitor 2019*.

Winkler, H. (2007). Energy policies for sustainable development in South Africa. *Energy for Sustainable Development*, *11*(1), 26–34. https://doi.org/10.1016/S0973-0826(08)60561-X

World Bank. (2015). World Bank Open Information Policy. In *world bank*. https://data.worldbank.org/

York, R., & Bell, S. E. (2019). Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. In *Energy Research and Social Science* (Vol. 51, pp. 40–43). Elsevier Ltd. https://doi.org/10.1016/j.erss.2019.01.008

Yue, X., Patankar, N., Decarolis, J., Chiodi, A., Rogan, F., Deane, J. P., & O'Gallachoir, B. (2020). Least cost energy system pathways towards 100% renewable energy in Ireland by 2050. *Energy*, *207*, 118264. https://doi.org/10.1016/j.energy.2020.118264

Zoundi, Z. (2017). CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. In *Renewable and Sustainable Energy Reviews* (Vol. 72, pp. 1067–1075). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.10.018

Zwaan, B. Van Der, Jan, G., Kober, T., Longa, F. D., & Laan, A. Van Der. (2018). An integrated assessment of pathways for low-carbon development in Africa. *Energy Policy*, *117*(August 2017), 387–395. https://doi.org/10.1016/j.enpol.2018.03.017

APPENDIX

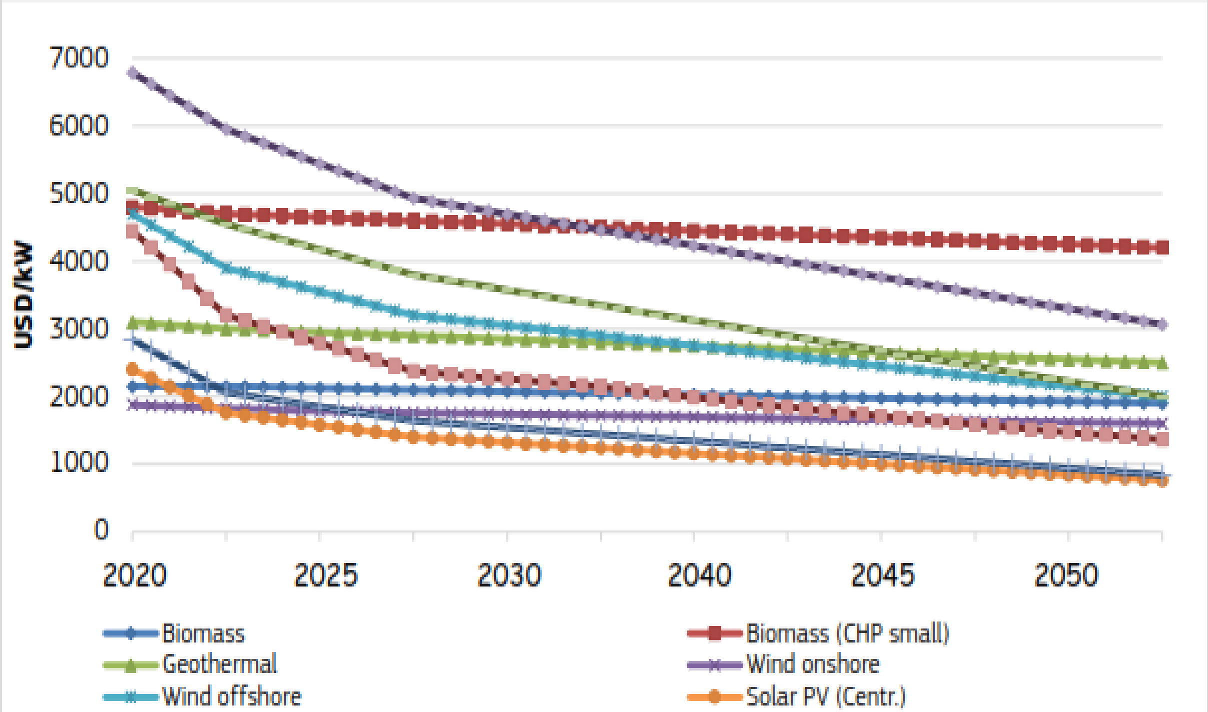
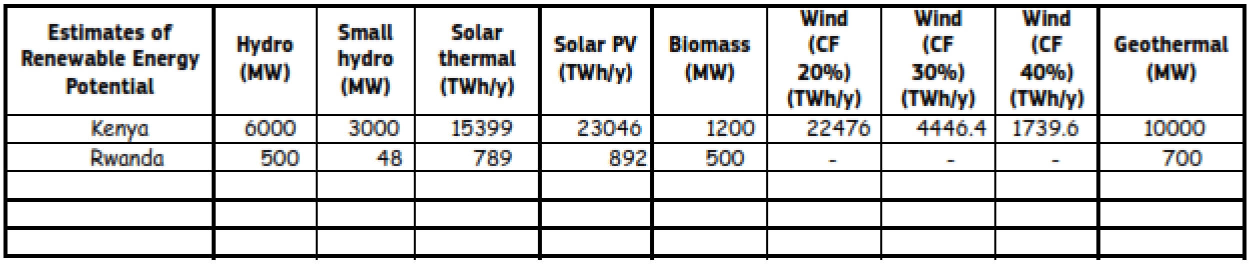


Figure 11 Assumptions on levelized cost developments 2020-2050



Estimates of Renewable Energy Potential	Hydro (MW)	Small hydro (MW)	Solar thermal (TWh/y)	Solar PV (TWh/y)	Biomass (MW)	Wind (CF 20%) (TWh/y)	Wind (CF 30%) (TWh/y)	Wind (CF 40%) (TWh/y)	Geothermal (MW)
Kenya	6000	3000	15399	23046	1200	22476	4446.4	1739.6	10000
Rwanda	500	48	789	892	500	-	-	-	700

Figure 12 Renewable energy potential in the Kenya and Rwanda

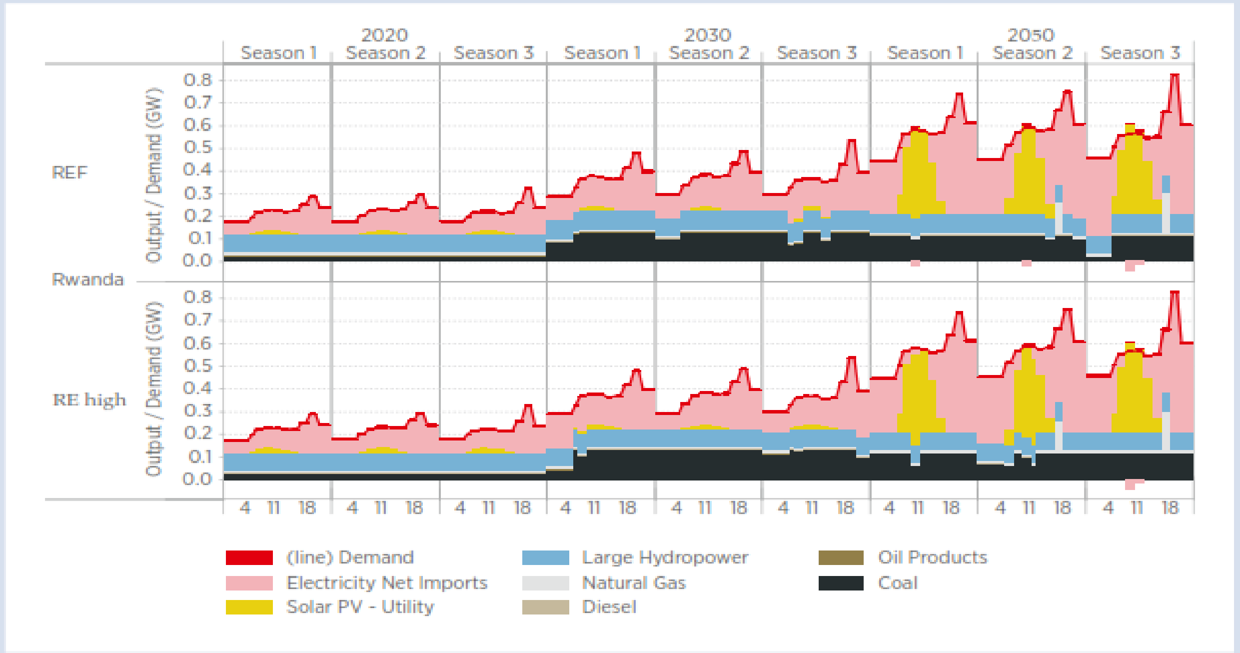


Figure 13 Dispatch pattern of Rwanda

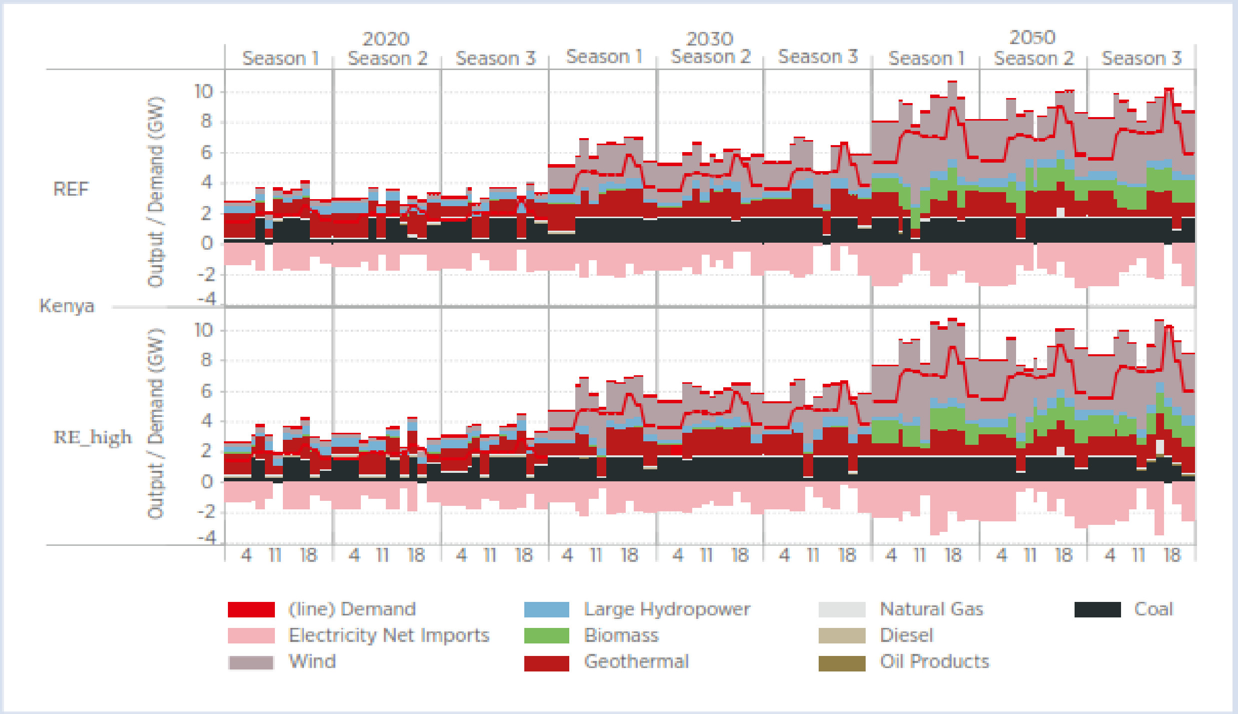
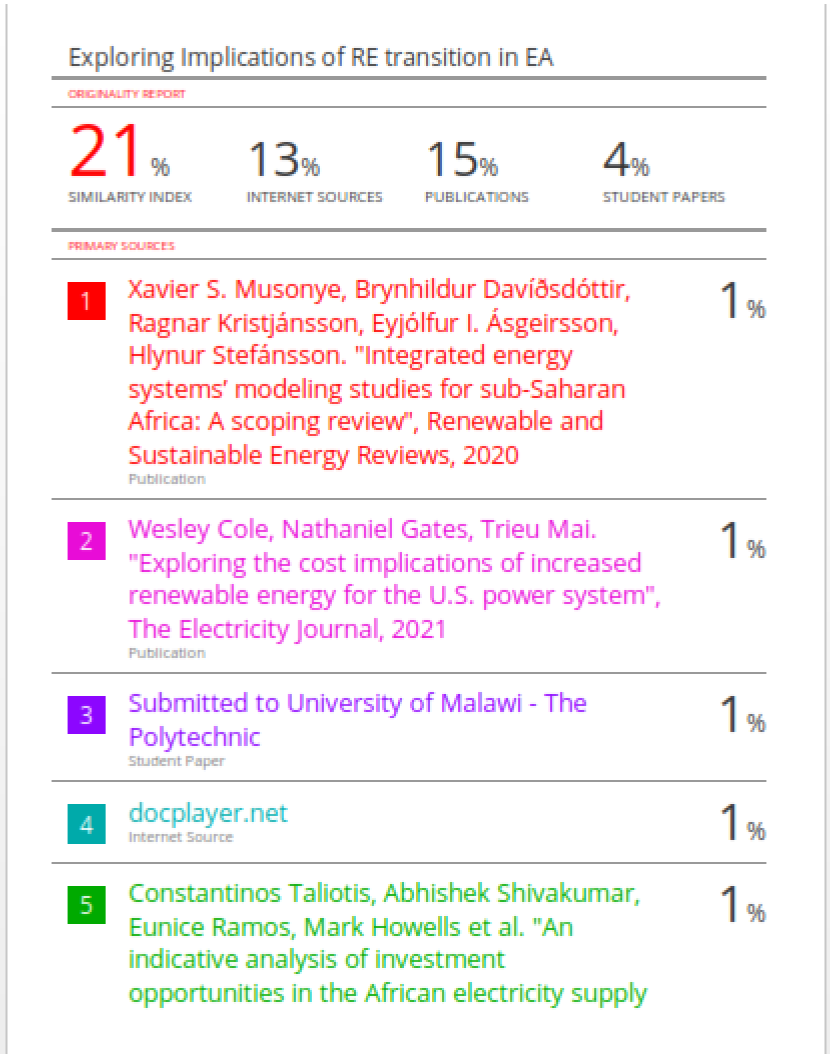


Figure 14 Dispatch pattern of Kenya



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