Addressing the Challenges of 100% Electricity Supply with Renewable Energy Sources in Kenya's National Grid

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Abstract

The response to climate change demands countries to immediately replace fossil fuels with low carbon energy sources like renewables. On its part, Kenya targets a 30% reduction in greenhouse gas emissions by 2030 compared with business-as-usual mainly through scaling up of renewables' contribution to power generation. The current installed capacity of renewables in Kenya is 73%, mainly from geothermal, hydro, and wind, while generation contribution is 88% and the national access rate is 76%. In 2018, with a view of meeting climate change and universal access targets, the president announced the government's intention to supply 100% of Kenya's electricity demand with renewables. However, he did not elaborate on how this could be achieved. Past studies have indicated insufficient historical evidence for the feasibility of 100% renewable energy supplies at country, regional or larger scales. Therefore, the objective of this dissertation is to investigate how to address the challenges of 100% electricity supply with renewable energy sources in Kenya's national grid through demand-side management and renewables adoption by residential consumers.

The main part of this research was based on two questionnaire surveys and field interviews. The first questionnaire was administered among 250 residential electricity consumers in Nairobi County (urban), Makueni, and Uasin Gishu counties (largely rural) between October and November 2018. The second questionnaire was administered among 31 experts in Kenya's energy sector between May and July 2019. I also carried out an extensive review of government documents on the energy sector and reports from several local and international organizations. Finally, I conducted interviews on seven informants working for the Ministry of Energy and Petroleum in September 2019.

From the interviews, documents, and reports review, I found that Kenya's initial energy policy formulation and evolution were heavily influenced by financial partners. However, over time, the local political dynamics have played a significant role especially in favor of generation from renewables with laws being passed immediately before or after a general election. There has also been a continuous increase in the share and the diversity of investments on renewables. The prospects of renewable energy growth are highly dependent on the sustainability of the existing political will and external financial support, litigation activities, and technological advancements.

The results of the questionnaire survey among energy experts showed that about 76% and 41% of the respondents strongly agreed or agreed that Kenya could meet its electricity and entire energy demand respectively for 2030 with renewable energy resources and higher percentages of about 89% and 71% responded similarly for 2050. The respondents indicated that the most viable methods for dealing with variability under 100% renewable energy sources electricity supply are: using non-variable sources to help match demand with supply (81%), regional (74%) and national (61%) interconnection of geographically dispersed renewable energy sources, providing 100% of rural households electricity demand with renewables (71%), and applying demand-response management and smart grid (68%). In addressing transmission and universal access challenges, the use of mini-grids run by renewables (76%) is economically more viable than extending the national grid (41%). Another salient finding is that about 65% of the experts consider the electricity supply stability under 100% renewables as far better or better than now.

Among the residential consumers' respondents, I found a low level of familiarity with smart meters (24%), smart grid (20%), and demand-side management (43%). However, to avoid power outage during peak hours, 88% of them expressed their willingness to shift the period they use electricity. More respondents in the rural (96%) than urban (76%) counties were interested in adopting renewables for their entire electricity consumption mostly for solving frequent power outages and high energy costs of grid electricity. Similarly, more in the rural (86%) than urban (63%) counties showed their interest in generating and selling renewables to the grids subject to subsidies availability. I also found that even though about 98% of the respondents showed their concerns for environmental conservation, this did not motivate them much to invest in renewables. Currently, in their attempts to invest in renewable energy sources, the residential consumers were challenged by the high cost of equipment (49%) and the intermittent nature of renewables (27%).

Reflecting on these findings, I conclude that Kenya has adequate renewable energy resources and the capacity to overcome the variability, transmission, and access challenges to supply its electricity demand with 100% renewables by 2030. In this regard, demand-side management and residential electricity consumers' who have shown interest in adopting renewable energy technologies will play a critical role. To centralize their contribution, I recommend consumer education on the importance of demand-side management and the provision of incentives for purchasing renewable energy generation accessories.

Keywords: 100% renewable energy, climate change, demand-side management, environmental conservation, renewable energy potential, residential electricity consumers

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List of Abbreviations

BIPV	Building Integrated Photovoltaics
EAPL	East African Power and Lighting Company Limited
EPPs	Emergency Power Producers
EPRA	Energy and Petroleum Regulatory Authority
EPT	Energy and Petroleum Tribunal
ERB	Electricity Regulatory Board
ERC	Energy Regulatory Commission
ET	Energy Tribunal
FFs	Fossil Fuels
FiT	Feed-in-Tariff
GDC	Geothermal Development Corporation
GHG	Greenhouse Gas
IEA	International Energy Agency
IFC	International Finance Corporation
IHDs	In-Home Displays
IMF	International Monetary Fund
INDCs	Intended Nationally Determined Contributions
IPO	Initial Public Offering
IPPs	Independent Power Producers
KES	Kenyan Shilling
KETRACO	Kenya Electricity Transmission Company Limited
KNBS	Kenya National Bureau of Statistics
KOSAP	Kenya Off-Grid Solar Access Project
KPLC	Kenya Power and Lighting Company
kWh	Kilowatt-hour
kWp	Kilowatt peak
LCPDP	Least Cost Power Development Plan
LTWP	Lake Turkana Wind Power Project

MoEP	Ministry of Energy and Petroleum
Mt	Metric tons
MW	Megawatt
NESC	National Economic and Social Council
NOAA	National Oceanic and Atmospheric Administration
NSE	Nairobi Stock Exchange
PHES	Pumped Hydro Energy Storage
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REA	Rural Electrification Authority
RERAC	Renewable Energy Resource Advisory Committee
REREC	Rural Electrification and Renewable Energy Corporation
SAPs	Structural Adjustment Programs
SDGs	Sustainable Development Goals
SE4All	Sustainable Energy for All
SPV	Special Purpose Vehicle
TRDC	Tana River Development Company Limited
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
VAT	Value Added Tax
VRE	Variable Renewable Energy
WBG	World Bank Group
w/m^2	Watts per square meter

Chapter 1 Introduction

1.1 Background

Globally, the earth's surface temperatures in 2019 were the second warmest since modern recordkeeping began in 1880. With 2016 ranking first, the past five years (2015-2019) have been the warmest of the last 140 years (Arguez et al., 2020; NOAA National Centers for Environmental Information, 2020). In 2018, the IEA assessed the impact of fossil fuel use on global temperature increase. They found that CO_2 emitted from coal combustion was responsible for over 0.3°C of the 1°C increase in global average annual surface temperatures above pre-industrial levels, making it the single largest source of global temperature increase. The largest contributor to the growth in emissions observed in 2018 was coal-fired power plants with an increase of 2.9%, or 280 Metric tons (Mt), compared with 2017 levels, exceeding 10 gigatons for the first time. Hence, electricity generation from coal accounted for 30% of global CO_2 emissions (IEA, 2019).

With little prospect of decreasing energy consumption globally this century given that over 10% of the global population live in extreme poverty and without access to electricity, there is a need to replace fossil fuel carbon sources to reduce catastrophic global warming (Heard et al., 2017). In this regard, previous studies have proposed renewable energy sources as the best alternative (Brown et al., 2018; Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2011). In 2018, for example, the transition to renewables in the power sector resulted in the avoidance of 215 Mt of emissions without which emissions growth would have been 50% higher (IEA, 2019).

In Kenya, the national access rate grew by more than 3 times to about 76% between 2013 and 2019. With the majority of those lacking access being rural residents, the government plans to achieve universal access by 2022 (Directorate of Electrical Power Development, 2019). Given the sparse population in the rural areas and the high cost of connection to the national grid, I argue that renewables will play a key role in achieving this objective. Currently, some consumers without access have invested in renewables such as solar PV as an alternative electricity source (Government of Kenya, 2018).

As energy demand has risen rapidly in Kenya, the Kenyan government has set ambitious goals for 2030 (Government of Kenya, 2007). The government has also designated energy as a critical enabler of Vision 2030 and The Big Four Agenda (2018-2022) which focuses on the 4 pillars: manufacturing, food security and nutrition, universal health coverage, and affordable housing. However, the main challenges facing Kenya's energy sector are generation capacity, its dependence on hydroelectric generation, high peak demand, and frequent power outages. In the case of peak demand or power outages, the public utility buys supplies from emergency power producers (EPPs) that generates power either from medium-speed diesel (MSD) plants or high-speed diesel plants. The cost of these private energy supplies is high and makes the electricity sector one of the main sources of CO_2 emissions in the country (Kenya Power, 2018; Ministry of Energy and Petroleum, 2013).

In solving the above challenges with budgetary and environmental constraints, the government through Kenya's Intended National Determined Contributions (INDCs) and the Kenya National Climate Change Action Plan has focused on expanding power generation from geothermal, hydro, solar, wind and biomass sources. Currently, Kenya's installed capacity is 2,813 MW, while the total effective capacity is 2,743 MW. The current installed capacity of renewables in Kenya is 73% while generation contribution is 88%. The generation mix consist of geothermal (42%), hydro (31%), wind (14%), solar (1%) and biomass (0.004%). The share of geothermal grew from 14% in 2013 to over 40% in 2019 significantly reducing overreliance on hydro (Ministry of Energy and Petroleum, 2013; Directorate of Electrical Power Development, 2019; EPRA, 2020). This was occasioned by the annual fluctuation of hydropower thus the government identified geothermal as the least-cost choice to be used as the baseload (Government of Kenya, 2018). In 2018, the president announced the government's intention to supply 100% of Kenya's electricity demand with renewables. However, he did not elaborate on how this could be achieved (PSCU, 2018).

Critics have raised several issues on the viability of 100% electricity supply with renewables. In particular, they claim that the proponents of renewable energy sources are not taking sufficient consideration about the variability of wind and solar, storage technologies, overall system costs, resource availability, and social acceptance (Heard et al., 2017; Trainer, 2012, 2013). Some have highlighted neglect to transmission or distribution networks. They added a near-total lack of historical evidence for the feasibility of a 100% renewable-electricity systems operating at country, regional, or larger scales (Heard et al., 2017).

In Kenya, the existing studies have neither addressed the overall concerns nor those particular to the country. Instead, they have focused on areas like the technical renewable energy potential (Kiplagat et al., 2011), consumer satisfaction in Kenya's energy sector (Mutua et al., 2012), individual renewable energy technologies like solar PV (George et al., 2019; Bawakyillenuo, 2012), and feed-in-tariffs (Boampong and Phillips, 2016). This dissertation seeks to fill these gaps by utilizing the knowledge and experience of experts and residential consumers in Kenya's energy sector. The questions are: does Kenya have the capacity to supply 100% of its electricity demand with renewables? To what extent can demand-side management contribute to 100% renewable energy supply? To what extent are Kenya's residential electricity consumers willing to adopt renewable energy resources?

1.2 Research objectives

This dissertation seeks to investigate how to address the challenges of 100% electricity supply with renewable energy sources in Kenya's national grid. In particular, I address the following specific objectives:

i) To trace the historical development of energy policies and the future of renewable energy in Kenya
ii) To investigate Kenya's capacity to supply 100% of its electricity demand with renewable energy sources
iii) To investigate how to address variability and transmission challenges under 100% electricity supply with renewable energy sources in Kenya's national grid
iv) To determine the future contribution of demand-side management in achieving 100% electricity supply with renewable energy sources in Kenya
v) To investigate regional contexts of residential consumers' decision-making for adopting renewable energy technologies in Kenya

1.3 Study areas

To achieve the above objectives, I administered a questionnaire to 31 experts in Kenya's energy sector who deal with policy formulation, electricity generation, transmission, and distribution between May and July 2019. I contacted the experts working for technical departments in the Ministry of Energy and Petroleum, semi-autonomous agencies in the state department of energy, independent power producers (IPPs), and research institutions. The semi-autonomous agencies included the Energy and Petroleum Regulatory Authority (EPRA), the Kenya Power and Lighting Company (KPLC), the Kenya Electricity Generating Company (KenGen), Rural Electrification and Renewable Energy Corporation (REREC), Geothermal Development Company (GDC), and Kenya Electricity Transmission Company (KETRACO). Additionally, I interviewed seven informants working for the Ministry of Energy and Petroleum in September 2019. My choice of these experts was informed by their central role in policy formulation and implementation of renewable energy projects.

Apart from the experts, I also administered questionnaires among urban (Nairobi County) and rural (Makueni and Uasin Gishu counties) residential consumers in Kenya. My choice of these counties was based on their climatic conditions, urbanization level, household electricity demand, and economic activities. For example, Makueni County to the eastern part of the capital city generally receives less rainfall than Uasin Gishu County located in the western part. The three counties, therefore, are a good representation of urban and rural areas in Kenya. A summary of the study areas is given below.

Nairobi County is the capital city and the most populous urban county in Kenya with a population of 4,397,073, according to the 2019 census (KNBS, 2019). Its average annual precipitation is 926 mm with annual average daily temperatures ranges from 25.3°C to 12.6°C (KNBS, 2015a). Its total surface area is 697 km^2, which is classified as 100% urban (KNBS, 2015a). Currently, it has the nation's highest power consumption (45%) and is projected to remain so over the next 20 years. The County has benefitted from the World Bank-funded project of public/street lighting program (Kenya Power, 2018). Nairobi residents belong mainly to low, middle-high-income groups by residential areas (KNBS, 2015a). The average annual photovoltaic (PV) electricity output is 1530 kWh/kWp. The average annual wind power density ranges from poor to marginal (0-165 w/m^2) with some sites classified as very good (425-615 w/m^2) (Theuri, 2008; Ministry of Energy, 2013).

Makueni County is located about 130 km east of Nairobi County (Heap, 2015). It has a total population of 987,653 with sparse distribution, according to the 2019 census (KNBS, 2019). Its total surface area is 6,806 km^2, of which urban areas constitute about 1% (KNBS, 2015b). Its average annual precipitation is 596 mm. An annual average maximum and minimum temperatures are 28.2°C and 16.8°C, respectively (KNBS, 2015b). Some households were beneficiaries of the national efficient lighting program (Kenya Power, 2018). In 2012, the government built a 13.5 kWp solar plant, battery storage, and canopy at the Kitonyoni village trading center to supply electricity to about 3,000 residents (Heap, 2015). The average annual photovoltaic electricity output is 1573 kWh/kWp. The wind power density ranges from poor to marginal. Some spots are good (Theuri, 2008; Ministry of Energy, 2013).

Uasin Gishu County is dominated by the plateau environment, located about 310 km west of Nairobi (KNBS, 2015c). It has a total population of 1,163,186 (KNBS, 2019). Its average annual precipitation is 1100 mm. An annual average maximum and minimum temperatures are 23.3°C and 11.3°C (KNBS, 2015c). Its total surface area is 3,351 km^2, of which urban areas cover about 6%. The average annual photovoltaic electricity output is 1793 kWh/kWp while the average wind power density ranges from poor to marginal with some high-density spots (Theuri, 2008; Ministry of Energy, 2013). The County benefited from World Bank's street lighting project (Kenya Power, 2018).

1.4 Methodology

The main part of this dissertation is based on two sets of questionnaire surveys and field interviews. The first questionnaire survey was administered among 250 rural and urban residential consumers in the counties of Nairobi, Makueni, and Uasin Gishu between October and November 2018. The administration of questionnaires to the consumers was based on previous literature that indicated that a clear understanding of consumers' behavior was key in promoting the adoption of renewable energy sources (Kowalska-Pyzalska, 2018). The second questionnaire was administered among 31 experts in Kenya's energy sector between May and July 2019. I chose the experts based on their first-hand experience and a clear understanding of Kenya's energy sector. Additionally, their responses consider the technological and socio-economic factors that constitute critical determinants of renewable energy sources investment. Interviews were also conducted with seven experts working for the Ministry of Energy and Petroleum in September 2019. In the formulation of questionnaires and to better understand the significance of the data collected, I reviewed past studies on 100% electricity supply with renewables, demand-side management, and consumers' adoption of renewable energy technologies. Besides, I examined reports from government and international organizations like the World Bank, government studies on renewable energy planning and investment, energy policies, and political parties' manifestos.

1.5 Literature review

Climate change and energy-security issues require changes in the world's energy infrastructure toward 100% renewable energy sources (Jacobson and Delucchi, 2011). Currently, some countries (e.g., Bangladesh, Cambodia, Columbia, Ethiopia, Ghana, Mongolia, Vietnam) and states (e.g., Hawaii, California) aim to achieve 100% renewable energy electricity supply by 2050 (Hansen et al., 2019). Other countries have achieved or come close to achieving a 100% renewable grid. These countries use hydropower or geothermal. However, for hydropower most good sites have been developed. On the other hand geothermal is limited by geographic distribution (Kroposki et al., 2017). This implies that in the future, the variable renewable energy sources (VREs) like solar PV and wind will play a significant role. Apart from the variability of these VREs, their geographical distribution mostly far away from demand centers presents a significant obstacle to the cost of transmission (Delucchi and Jacobson, 2011). To achieve a 100% electricity supply with renewables, these challenges ought to be conquered.

In achieving a 100% electricity supply with renewables, previous studies have demonstrated that initially there is a need to determine the renewable energy economic potential which is a subset of the technical potential (Brown et al., 2016; Heard et al., 2017). The second step would be to compare the economic potential and the energy demand in assessing the capacity to supply the entire energy demand with renewables (Jacobson and Delucchi, 2011). In Kenya, there have been studies and government publications that determined the technical renewable energy potential (Kiplagat et al., 2011; Ministry of Energy and Petroleum, 2015; Theuri, 2008). However, these studies did not determine the renewable energy economic potential nor were there any attempts to compare it with the existing or projected power demand. Therefore, this dissertation aims to fill this gap.

Previous studies indicate that demand-side management is vital for transitioning to 100% renewable energy systems in all sectors while remaining within sustainable resource limits (Davito, Tai, Uhlaner, 2010; Hansen et al., 2019; Walawalkar et al., 2010). To flatten the load curve, they argue, the daily peak demand should be shifted towards less expensive baseload generation or renewables (Davito et al., 2010). In this case, the smart grid provides the scale and scalability to make demand-side management cost-effective and convenient. For example, it can help to diversify pricing practices, encourage energy-saving, and balance electric loads to reduce blackouts (Chawla et al., 2020). Given the central role that demand-side management will play in the future energy systems, its successful implementation necessitates consumers' acceptance. For Kenya in particular, acceptance by residential consumers is critical since most of the energy growth has been experienced in this sector (Government of Kenya, 2018). However, less focus has been placed on this type of solution such as reducing consumer energy demands. Besides, the implementation of demand-side management in Kenya has been hindered by the available technologies necessitating the need to investigate possible future contributions.

The role of the residential electricity consumers in the transition to 100% electricity supply with renewables is vital. This is more so for Kenya where the residential sector accounts for 31% of the total electricity consumption (KPLC, 2017). This could even increase further as the government plans to connect consumers in the sparsely populated rural areas. With the increased connectivity, technical transmission losses are expected to increase to more than 20% as a result of low voltage connections that have typically higher losses (Government of Kenya, 2018). In this regard, previous studies have indicated that favorable economics prosumers are likely to play a significant role in investing in generation and storage (Shi, 2016). However, there has been limited investments by consumers (Masini and Menichetti, 2012). Some studies indicated that consumers' investment in renewable energy sources is preceded by an understanding of their awareness, environmental attitudes, and energy consumption patterns, contextual and habitual factors. These factors are country or region specific (Chawla et al., 2020; Kowalska-Pyzalska, 2018; Masini and Menichetti, 2012; Palmer et al., 2015). This study seeks to understand Kenya's electricity consumers' attitudes towards renewable energy sources.

1.6 Significance of the study

This study provides an empirical basis to understand the evidence behind propositions for a 100% renewable energy for Kenya. The outcomes are expected to provide a better understanding of renewable energy resource potential and consumer behaviors in Kenya. This study can help Kenya's multilateral and bilateral development partners to make more informed decisions on funding Kenya's major renewable energy projects.

Locally, the government aims to achieve universal access by 2022. It has also identified energy as one of the main pillars for achieving Vision 2030. This dissertation responds to objective 7 of the Sustainable Development Goal (SDGs) that calls for the provision of affordable, reliable, and clean energy by 2030. Kenya is a signatory to the United Nations Decade of Sustainable

Energy for All (SE4All). This dissertation also sheds light on Kenya's National Determined Contribution (NDC) under the Paris Agreement of reducing the country's greenhouse gas emissions by 30% by 2030 compared to business as usual.

In terms of research fields, this study will contribute to a relatively new research field of a 100% renewable energy study that was established less than 20 years ago. The major regions and countries in the world including Sub-Saharan Africa, are not yet well covered in this field. It will also contribute to the field of climate change as studies have shown that fossil-fuel electricity generation accounts for more than 30% of global CO_2 emissions the main cause of climate change. Finally, the actual supply of electricity with renewables will make Kenya a model for regional and international significance as the world looks into ways of increasing the share of renewables to mitigate against the impacts of climate change.

1.7 Structure of the dissertation

This dissertation consists of seven chapters. The first chapter clarifies the research objectives, general methodology, and the significance of this dissertation. In the second chapter, I traced the historical development of Kenya's energy policies to gain insight into the changes over time and the impact it has had on the deployment of renewable energy resources. In chapter 3, I investigate Kenya's capacity to supply 100% of its electricity demand with renewable energy sources. Chapter 4 investigates how to address the variability and transmission challenges under a 100% electricity supply with renewable energy sources in Kenya's national grid. In chapter 5, I examine the future contribution of demand-side management in achieving a 100% electricity supply with renewable energy sources in Kenya. In chapter 6, I investigated regional contexts of residential consumers' decision-making for adopting renewable energy technologies in Kenya. The last chapter summarizes the main findings and provides recommendations. The structure and the link between the different chapters is given in figure 1.1.

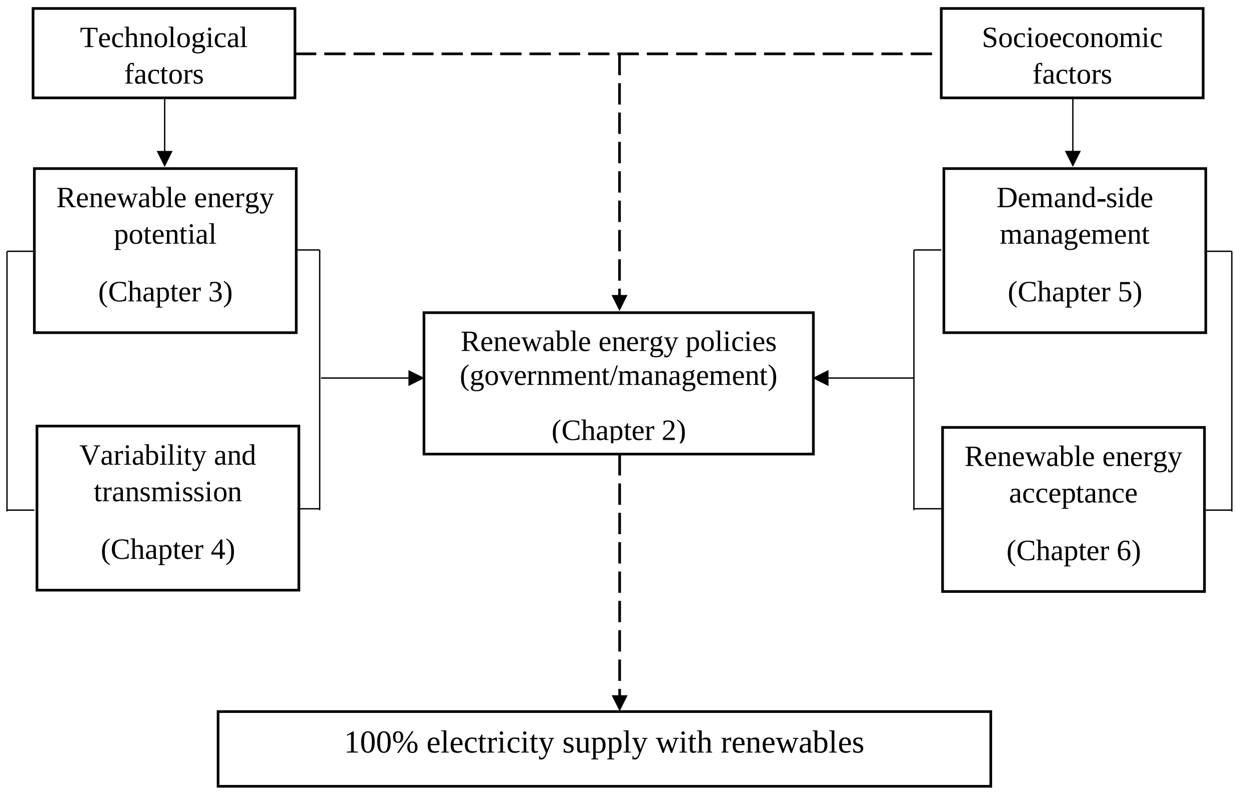

Figure 1.1 Structure of the dissertation[1]

[1] This figure shows the relationship and the link between the chapters. The continuous line is the interaction of factors while the dashed lines shows the path to 100% electricity supply with renewables.

Chapter 2 The Historical Development of Energy Policies and the Future of Renewable Energy in Kenya[2]

2.1 Introduction

Globally, renewable energy technologies provide opportunities for developing countries like Kenya to increase their generation capacity and solve electricity sector challenges. Past studies have shown that policies determine the extent to which a nation adopts renewable energy resources (Boampong and Phillips, 2016; Romano, Scandurra, Carfora, and Fodor, 2017).

This chapter traces the historical development of Kenya's energy policies to gain insight into the changes in the deployment of renewable energy resources. This chapter also identifies factors that have contributed to the changes. It also looks into actual renewable energy investments and the trend over this period. I argue that without this understanding it would be difficult to understand the future of renewable energy in Kenya.

This chapter traces the historical development of energy policies and projects in Kenya in two main periods: pre-reform (1963-1995) and post-reform (1996-2020). In each period, stakeholders guided by different political, economic, and environmental factors shaped the policies and the level of investment on renewables. Historically Kenya's energy policies have been greatly shaped by external pressures, financing, and climatic changes.

2.2 Methodology

For this chapter, I carried out an extensive analysis of published works and government studies. I collected information from journal papers, government and international organizations reports, laws, policies, political parties' manifestos, and newspapers. Data on renewable energy generation was collected from the World Bank and reports from Kenya Power and Lighting Company (KPLC). Additionally, to clarify how the different factors influenced policy formulation in the past and their possible contributions in the future, I interviewed seven officials from the Ministry of Energy and Petroleum in September 2019. I used chain-referral sampling to identify the key interviewees. The selection of these interviewees was largely guided by my network and their involvement with policy formulation. Most of the interviewees were directly involved with policy formulation and

[2] Part of this chapter was presented at the International Conference on Environment and Life Science (ICENLISC-19). Brisbane, Australia. December 16-17, 2019.

implementation. I also incorporated my personal experience together with other published studies from other jurisdictions to gain more insight into the Kenyan situation.

2.3 Kenya's pre-reform energy policies (1963-1995)

This period was characterized by energy project implementation before policy formulation. After independence in 1963, Kenya's power generation was dominated by fossil fuels and hydropower (World Bank, 1971). In 1964, the Tana River Development Company Limited (TRDC) was formed to develop the hydro potential along the Tana River. This resulted in the construction of the Seven Forks Scheme, a set of Kenya's large hydropower developments, such as Kindaruma dam in 1968, Kamburu dam in 1975, Gitaru dam in 1978, Masinga dam in 1981 and Kiambere dam in 1988 (Hughes, 1984; Ministry of Energy and Petroleum, 2018). These projects were majorly financed by loans and grants from the World Bank (World Bank, 1971).

Data from the World Bank show that from the 1970s, the share of renewable energy generation increased continuously, peaking at 96% in 1988-89 and 1992-93. The trend of growth was synonymous with that of hydropower generation (World Bank, 2014a) (Figure 2.1). Donor investments were catalytic in the development of solar PV from the 1970s to the middle of the 1980s and eventually triggered the private sector involvement. Kenya became known as a "donor hub" allowing the solar PV market to develop early (Boampong and Phillips, 2016).

The Government recognized the need to formulate a comprehensive national energy development plan after the 1973-74 and the 1978 energy crises. As a result, in 1978, the National Power Development Plan for 1978-2000 was formulated and the Ministry of Energy was established in December 1979 (World Bank, 1983). The interview indicated that these developments were heavily influenced by the World Bank and other development partners. Before this, the power sector was run by the East African Power and Lighting Company Limited (EAPL) formed in 1922, and Kenya Power Company Limited (KPC) formed in 1955. In 1983, EAPL changed to Kenya Power and Lighting Company (KPLC) (World Bank, 1983).

Geothermal resource exploration that started in the 1950s, resulted in the government's decision to construct three plants with a capacity of 15 MW each. The first unit was brought online in July 1981, the second in December 1982 and the third in April 1985 (Ofwona, 2002). These were the first geothermal power stations in Africa. In 1982, the Parliament passed the Geothermal Resources Act (Geothermal Resources Act, 2012). It authorized the government to control and exploit geothermal resources. In 1983, the government stated its intention to focus on the development of geothermal and hydro while thermal electricity generation was to serve emergencies (World Bank, 1983).

In the late 1980s, the government expanded hydropower generation beyond the Tana River and Turkwel Hydroelectric Power Station (106 MW) was commissioned in 1990. The government also explored wind power generation with the first six turbines (0.35 MW each) installed in 1993 financed mainly through a Belgian government loan (Kiplagat et al., 2011).

The electricity sector reform policies in Kenya can be traced back to the 1980s just like in many other African countries. The World Bank Group (WBG) and the IMF (Mills, 1989) promoted structural adjustment programs (SAPs). In response, the Kenyan government enacted the Restrictive Trade Practices, Monopolies, and Price Control (RTPMPC) Act of 1989. It aimed at reducing direct price control and promoting competition. As Kenyan resistance to reforms and corruption continued, the World Bank and other development partners imposed an aid embargo on Kenya between 1991 and 1994. This adversely affected the power sector (Eberhard et al., 2018).

In 1996, the government in collaboration with IMF and World Bank formulated a policy paper on the Economic Reforms for 1996-1998 (Government of Kenya, 1996). It aimed to reform the energy sector by separating the regulatory and commercial functions and promoting private-sector investment. It also outlined the commencement of separating generation, transmission, distribution (Eberhard et al., 2018).

2.4 Kenya's post-reform energy policies (1996-2012)

In 1996, partly urged by multilateral and bilateral development institutions, the national government liberalized its energy sector. My interviewees revealed that the government also attempted to solve electricity sector challenges to win the general elections in 1997. In this regard, the first action after liberalization involved the invitation of Independent Power Producers (IPPs) as a stopgap measure to address the frequent power outages caused by drought (Eberhard et al., 2018). For example, IPPs utilizing diesel generators: Westmont (46 MW) sponsored by a Malaysian firm and Iberafrica (44 MW) established as a partnership between Union Fenosa (Spain, 80%) and KPLC Pension Fund (Kenya, 20%) were the first to be invited (Eberhard et al., 2018). A shortage of state funding and severe drought in the late 1990s galvanized private sector involvement in electricity generation between 1997 and 1999 (Eberhard et al., 2018).

The Electric Power Act was enacted in 1997 (The Electric Power Act, 1997). However, the Act did not mention about renewable energy sources. It rather focused on the power sector reforms, including the dismantling of the KPLC monopoly. Consequently, the Kenya Electricity Generating Company (KenGen) was created in 1997 and assigned generation roles while KPLC retained the transmission and distribution roles. The Act also established the Electricity Regulatory Board (ERB) to set, review, and adjust consumer tariffs and promote competition. This allowed scaling up the contribution of IPPs in electricity generation through a competitive basis (The Electric Power Act, 1997).

The new government administration that was formed at the beginning of 2003 attempted to expedite the slow progress of energy sector reform. The Sessional Paper No. 4 of 2004 on Energy was the first policy that promoted electricity generation from renewable sources. For example, it gave a 10 year tax holiday for renewable energy power plants (Ministry of Energy, 2004). It promoted privately or community-owned renewable power plants. It then proposed partial privatization of KenGen by initially offering (IPO) 30% of its equity through Nairobi Stock Exchange (NSE) in 2006. The paper also allowed power generation companies to access bulk electricity consumers through the power transmission network (Ministry of Energy, 2004).

The proposals in the sessional paper were incorporated into Energy Act No.12 of 2006. The Act consolidated all laws related to energy and provided for a legal framework for the creation of the Energy Regulatory Commission (ERC), Rural Electrification Authority (REA) and the Energy Tribunal (ET). It put the responsibility of developing renewable energy frameworks on the Ministry of Energy (Energy Act of 2006, 2012). It mandated the REA to promote the use of renewable energy sources. The ERC became a sole energy regulatory agency to ensure genuine competition in the sector. It also approves the Power Purchase Agreements (PPA) and prepares the national energy plan (Boampong and Phillips, 2016). The ET is tasked with handling all the appeals related to the decisions of ERC (Energy Act of 2006, 2012).

In 2008, Kenya's Vision 2030 was announced to transform Kenya into an industrialized and middle-income country by 2030. The Vision was to increase power generation to 23,000 MW by 2030 from 1,310 MW in 2008 (Government of Kenya, 2018). As a result, it proposed the development of renewables. To accelerate investment in renewables, the government formulated the first feed-in-tariff (FiT) policy (Ministry of Energy, 2012). In the same year, the Geothermal Development Corporation (GDC) was formed as a Special Purpose Vehicle (SPV) for risky exploration, appraisal, and production-drilling aspects. It sells steam to KenGen and IPPs. Also, the Kenya Electricity Transmission Company Limited (KETRACO) was incorporated to plan, design, construct, own, operate and maintain high-voltage electricity transmission lines and fiber optic cables (Government of Kenya, 2018). During this period, development partners' and donors continued to contribute significantly to the growth and development of renewable energy. For example, the International Finance Corporation (IFC) invested US$5 million for market development of solar PV between 1998 and 2008 through its PV Market Transformation Initiative (Bawakyillenuo, 2012).

In 2009, the ERC established the Least Cost Power Development Planning Committee. The committee undertakes Kenya's power generation and transmission system planning through the Least Cost Power Development Plan (LCPDP). LCPDP 2011-2031 targets multiple renewable sources like geothermal, wind, hydropower, and biomass. It identified geothermal as the least-cost choice with a plan to use it as baseload (Government of Kenya, 2018). This specific focus on renewables led to the revision of the FiT policy in 2012. The revision standardized Power Purchase Agreements (PPAs) templates for negotiations, issued guidelines for connection of small-scale renewables to the grid, added a standardized application form and progress reporting/monitoring frameworks, changed FiT levels, and expanded the list of renewable energy sources qualifying for FiTs (Boampong and Phillips, 2016). Within 5 years of its implementation, the ERC approved FiT projects with a total generation capacity of over 180 MW (about 10% of the then installed capacity) (Eberhard et al., 2018).

Between 1996 and 2012, the share of renewables in the total energy supply widely ranged from 91% in 1996 to 47% in 2000 (Figure 2.2) as a result of severe drought (Eberhard et al., 2018; World Bank, 2014b). As a response, the Ministry of Energy arranged for Emergency Power Producers (EPPs) by signing contracts with Aggreko, Cummins, and Deutz for a combined rental capacity of 105 MW in 2000 and 2001 (Eberhard et al., 2018). In 2000, OrPower4 began to operate a 9 MW and an additional 4 MW for a total of 13 MW of geothermal. In 2003-2004, KenGen commissioned Olkaria II (70 MW) for geothermal installation. These increased the share of renewables to 84% by 2003 (World Bank, 2014a).

Hydroelectric plants and EPPs continued to play important roles in meeting Kenya's energy demands. For example, Aggreko was asked to supply 80 MW in 2006 and its contract was extended in 2007. By 2009, Aggreko was supplying 290 MW of emergency power (Eberhard et al., 2018). This dwarfed the 36 MW geothermal generation by OrPower4 and KenGen's Sondu Miriu (60 MW) and Sangoro (20 MW) hydropower plants in the same year. The share of renewables dropped to 55% then (Ministry of Energy and Petroleum Kenya, 2018). However, in 2010, KenGen commissioned Olkaria II (35 MW) and Olkaria IV (140 MW) geothermal plants in 2012 increasing the share of renewables to 75% (KenGen, 2020). Although several geothermal projects were commissioned during this period, its contribution was still low and the growth in renewables was synonymous with that of hydro continuously (World Bank, 2014a).

2.5 Kenya's energy policies after the new constitution (2013-2020)

Under Kenya's Constitution of 2010, the National and the County governments were mandated to review and align energy policies and laws. However, its implementation did not take effect until after the general elections of 2013. In election campaigns, the two leading coalitions, Coalition for Reforms and Democracy and the Jubilee Coalition, promised to reduce energy cost (Coalition for Reforms and Democracy, 2013; Jubilee Coalition, 2013). In particular, the Jubilee coalition's manifesto proposed the development of renewable energy by encouraging the participation of the private sector (Jubilee Coalition, 2013). When the Coalition took the helm of the government, it launched a program to increase electricity generation capacity by more than 5000 MW between 2013 and 2016. It also would reduce electricity costs to attract further investments in the manufacturing sector. The government envisaged that the private sector would develop 70% of the generation with GDC and KenGen developing the rest (Ministry of Energy and Petroleum, 2013).

The Public-Private Partnerships Act of 2013 (Revised 2015) additionally provided incentives for the private sector to finance, construct, develop, operate, or maintain public infrastructure projects (Public-private Partnerships Act, 2015). In 2014, the ERC approved the construction of Lake Turkana Wind Power Project (LTWP), the single largest private investment in Kenya's history, highlighting the central role of the private sector. To further promote investment in renewables, the Value Added Tax (VAT) (Amendment) Act of 2014 exempted VAT and import duties for supplies imported or bought for the construction of renewable energy power-generating plants or geothermal exploration (Value Added Tax (Amendment), 2014).

To align the energy sector to the devolved system of government, the Parliament passed the Energy Act in March 2019. The Act consolidated and updated all the laws on the energy sector. It promotes the growth of renewables through the creation of renewable energy resources inventory and resource maps which was to be done by the Ministry of Energy and Petroleum. These inventories and maps would reduce the burden on prospective investors in conducting exploratory studies. Under the Act, consumers (with less than 1 MW capacity) can supply any excess electricity to the grid. The Act further promoted renewable energy projects among local communities (Munyaka, 2019) whose dissatisfaction had led to delays or total abandonment of some projects (Kakah, 2015; Fayo, 2018). It also mandated community consultation in line with the 2010 Constitution (Munyaka, 2019). The Act had all renewable and geothermal energy resources vested in the national government. It created the following entities related to renewable energy The Rural Electrification and Renewable Energy Corporation (REREC), Renewable Energy Resource Advisory Committee (RERAC), Energy and Petroleum Regulatory Authority (EPRA) and the Energy and Petroleum Tribunal (EPT).

The Rural Electrification and Renewable Energy Corporation (REREC) replaced the Rural Electrification Authority (REA). The new entity has an expanded mandate, concerning renewable energy putting it at the center of policy formulation, research and development, international cooperation, and the promotion of renewable energy use amongst the local population (Energy Act, 2019). This came as a result of the government's recognition of the critical role of promoting the participation of the locals on renewable energy management (Munyaka, 2019).

RERAC, on the other hand, is a new inter-ministerial committee intended to advise the responsible Cabinet Secretary on matters concerning the allocation of renewable energy resources, the licensing of renewable energy resource areas, the management of water towers and catchment areas, the development of multi-purpose projects such as dams and reservoirs and the management and development of renewable energy resources. This was aimed at promoting inter-ministerial collaboration to quicken renewable energy project implementation (The Energy Act, 2019). The creation of the two entities shows the level of importance that the government places on renewable energy.

EPRA which is the successor to the Energy Regulatory Commission (ERC) will still retain regulatory control over the energy sector as a whole except for licensing of nuclear facilities and the regulation of downstream petroleum. EPT is the successor to the Energy Tribunal whose mandate was to hear appeals that may arise due to the decisions made by EPRA.

During this period, the share of renewables installed capacity increased from 62% in 2013 to 74% in 2020 (Figure 2.3). Consequently, the share of electricity generation from renewables increased from 69% in 2013 to 88% in 2015, and thereafter it has remained above 85% (World Bank, 2014b; Kenya Power 2016b; Directorate of Electrical Power Development, 2019; EPRA, 2020). In 2019, after the commissioning of the Lake Turkana Wind Power Project, the installed capacity of renewables exceeded the peak demand for the first time in Kenya's history (Directorate of Electrical Power Development, 2019). This signals Kenya's capacity to supply 100% of its electricity demand with the successful deployment of variable renewable energy sources. This occurred as a result of the renewed focus from the new government that led to the launching of several projects. For example, OrPower4 commissioned a geothermal capacity of 36 MW in 2013 and 26 MW in 2014. KenGen commissioned a geothermal capacity of 140 MW in 2014. Consequently, by the end of 2014, geothermal production (both public and private) surpassed hydropower for the first time in Kenya's history (Boampong and Phillips, 2016). This reduced the contribution of EPPs from 290 MW in 2009 to just 30 MW in 2014 (Eberhard et al., 2018). It also signaled a significant turning point in Kenya's renewable energy sector as the overall contribution of renewables was decoupled with hydro. As a result, from 2015, the fluctuation of hydro does not affect the overall renewables contribution. Between 2015 and 2019, KenGen (88%) and OrPower4 (12%) commissioned a combined geothermal capacity of 321.6 MW (Kenya Power, 2018).

The government also made efforts to diversify the investment in renewable energy sources. For example, KenGen commissioned 20.4 MW of wind in Ngong I phase 2 and Ngong II in 2015 (Kenya Power, 2018). In 2016, Biojoule Kenya Limited commissioned a 2 MW biogas plant (Kenya Power, 2018). Additionally, the Lake Turkana Wind Power Project with a capacity of 310 MW, the biggest in Africa, was commissioned in 2018. In terms of solar PV generation, although its use in Kenya began in the 1970s, it was until 2014 that Strathmore University became the first to connect its 0.25 MW to the national grid. In 2018, REA commissioned a 50 MW plant in Garissa County, the largest in East and Central Africa, bringing it to a total of 50.25 MW in the national grid. Currently, there are several solar PV projects at different stages of construction for connection to the national grid or mini-grids (Directorate of Electrical Power Development, 2019). The growth of investments in solar has been driven by competitive prices and opportunities under the FiT policy. I argue that to economically achieve universal access, the government ought to focus on deploying solar PV in remote areas.

By the end of 2019, Kenya had developed 13 IPPs' projects with approximately 30% of installed capacity and more are in development (Eberhard et al., 2018; Directorate of Electrical

Power Development, 2019). The interview revealed that Kenya could achieve such impressive growth in renewables as a result of a very strong political commitment from the President. Also, Kenya got the support of donor funding and scaled up the contribution of the IPPs. For example, in 2015, the World Bank approved US$457.5 million in funding to increase electricity access for Kenya's low-income households and to increase generation from renewable energy sources. The Olkaria geothermal project received funding from several donor agencies (Boampong and Phillips, 2016). The Kenya Off-Grid Solar Access Project (KOSAP) launched in 2017 was financed by the World Bank. The project aims to provide access to 1.3 million households in parts of the country that are not served by the national grid (Kenya Power, 2017). My interviewees indicated that Kenya has been able to attract huge financing from donors and private financiers as a result of the reforms in the energy sector that has improved the country's credit rating.

2.6 The prospects of renewable energy in Kenya

Past researches have shown that policies are major drivers for the renewable energy industry (Romano et al., 2017). The majority of my interviewees believe that the consolidation of energy sector policies into one Act of parliament in Kenya will simplify its implementation. They added that the four entities created by the Act together with specific measures will also promote the adoption of renewable energy technologies.

Despite the outstanding performance in terms of renewable energy policy formulation and implementation so far, the contribution of renewables could decrease in the future. For instance, only 58% of all the planned installations between 2020 and 2036 will be renewables as per the LCPDP 2017-2037. The rest will comprise of coal (30%) and gas turbine (12%) (Government of Kenya, 2018). This implies that unless the current political will is sustained, the share of renewables would reduce in the future. The interviews revealed that the growth of renewables will highly dependent on the growth of demand. Most of the interviewees foresee that exponential growth in demand especially from the manufacturing sector would force the government to invest more in fossil fuels to support industrial growth. In line with this, the interviewees also indicated that oil extraction in Kenya that started in 2019 could affect renewables either way depending on the government's strategy. For example, it could mean the availability of cheaper raw materials for running thermal power plants or the availability of funds for renewables investment.

Perhaps one of the greatest challenges to the sustainable growth of renewable energy in Kenya is the over-reliance on funding from multilateral and bilateral development institutions. The uncertainty on the availability of these funds represents a major impediment to the continuous growth of the industry. I argue that the availability of such funds will greatly reduce as a result of the impacts of Coronavirus pandemic which would significantly affect renewables investments. Also, the interviews revealed that bilateral loans have high-interest rates thus making renewable energy generation costs less competitive.

The Judiciary together with the civil society could play a key role in the growth of renewables in Kenya. For example, in 2019, the judges at the National Environmental Tribunal canceled the license for the construction of a coal power plant in Lamu citing poor environmental impact assessment and inadequate public participation. The locals wanted the government to set up clean energy plants instead of coal (Ochieng, 2019). In 2016, the High Court stopped the construction of Kinangop Wind Farm citing improper public consultations (Kakah, 2015).

My interviewees indicated that the recent trends of renewable energy technologies price reduction and efficiency improvements will likely lead to increased investments in renewables. They added that the increase in investment could be boosted by direct government interventions through tax reliefs that would lead to further price reductions. The other aspect is the technical breakthrough in renewables conversion efficiencies and cost reductions. For example, a recent study showed the possibility of doubling the conversion efficiency of solar PV to over 45% (Geisz et al., 2020). Most of the interviewees agree that this would make solar PV more attractive to consumers and power producers.

2.7 Summary

Since independence, the energy policies and project implementation have evolved through several phases. Initially, project implementation preceded policy formulation up to the late 1970s. Thereafter, projects have been implemented following well-established policy frameworks. The initial policy formulation and evolution were heavily influenced by pressure from multilateral and bilateral financial institutions. However, over time, the local political dynamics have played a greater role in policy formulation especially in favor of generation from renewables with laws being passed immediately before or after a general election. As a result, there has been a continuous increase in the share and the diversity of renewables in the national grid. Through this, I found out that Kenya has created a relatively robust regulatory framework for a renewables' pathway coupled with heavy financial investments.

The new energy act provides an opportunity for further growth of renewables by promoting the adoption of renewables by commercial and residential consumers. It also lays down an elaborate institutional framework that would further increase the share of renewables in the national grid. The main challenge now is how to maintain the growth in renewables with a projected exponential increase in electricity demand. In conclusion, a sustained political will together with a clear understanding of the country's renewable energy potential, would be critical in successfully implementing the new act and further growth in renewables. In the following chapter, I examine Kenya's capacity to supply 100% of its electricity demand with renewable energy resources.

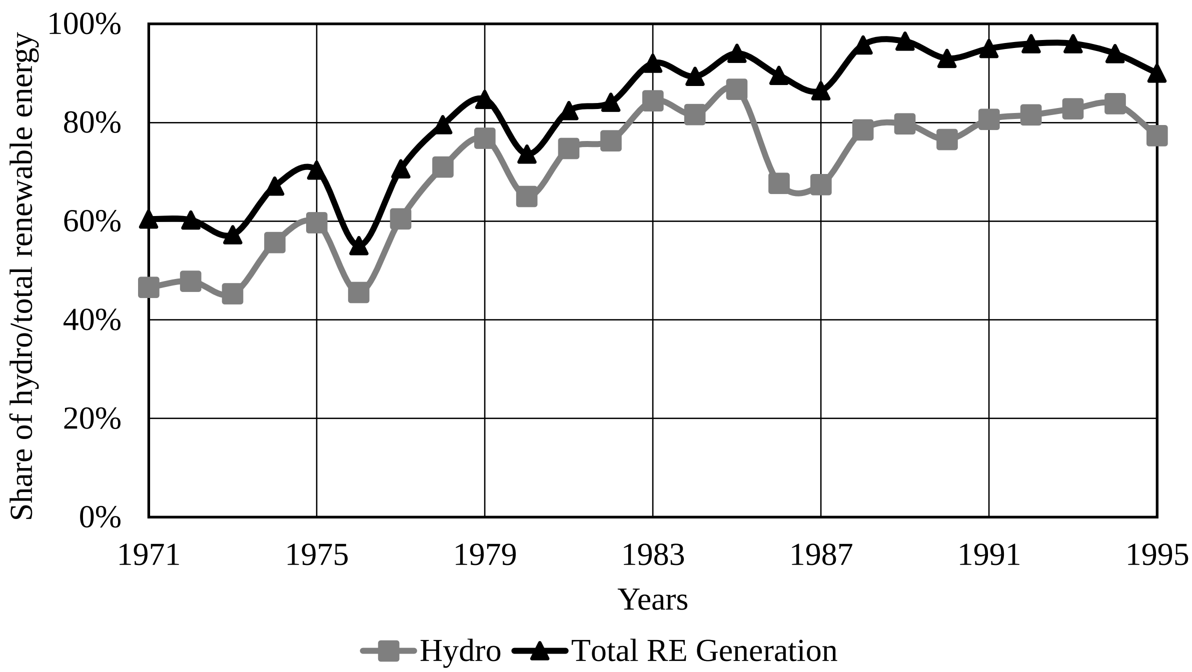

Figure 2.1 Share of hydro and total renewable energy in the national grid (1971-1995)
Source: Compiled from World Bank (2014a, 2014b)

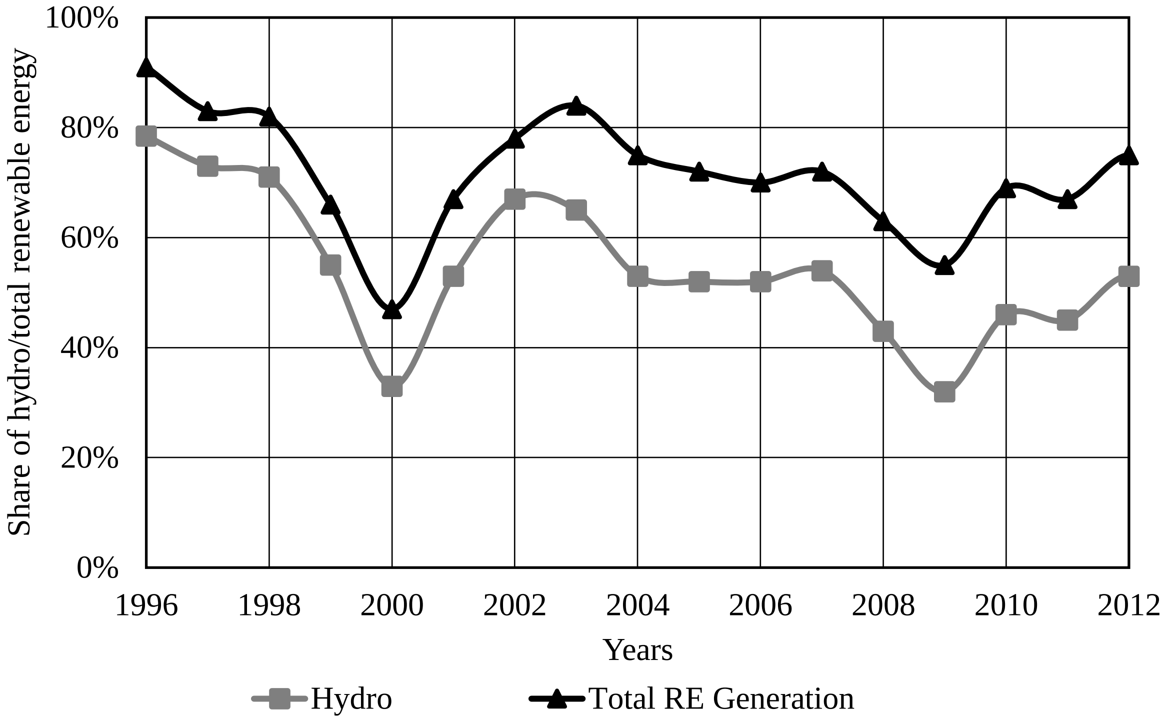

Figure 2.2 Share of hydro and total renewable energy in the national grid (1996-2012)

Source: Compiled from World Bank (2014a, 2014b)

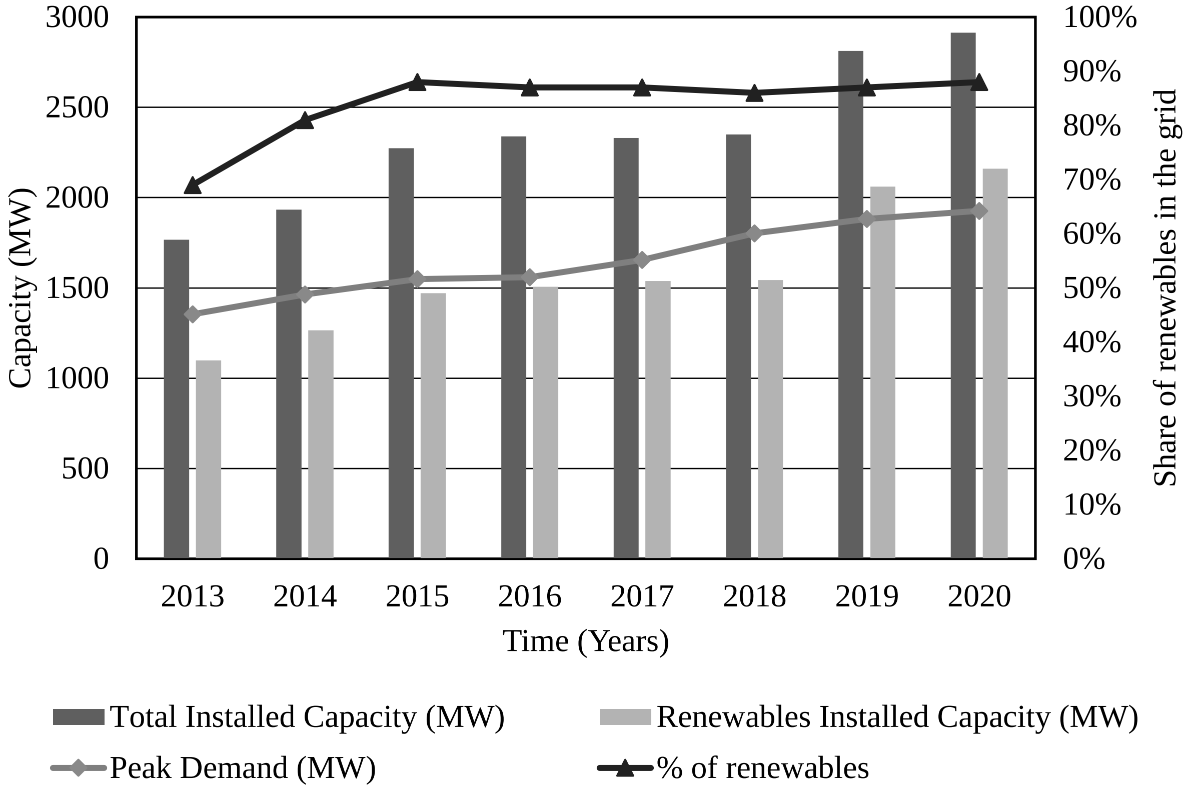

Figure 2.3 Kenya's electricity installed capacity, share of renewables and peak demand (2013-2020)

Source: Compiled from Directorate of Electrical Power Development (2019), EPRA (2020) and Kenya Power reports (2016b, 2017, 2018)

Chapter 3 An Analysis of Kenya's Capacity to Supply 100% of its Electricity Demand with Renewable Energy Sources[3]

3.1 Introduction

If the current warming trend continues, the global temperature is projected to rise by 1.5^0C between 2030 and 2052 (Cook et al., 2013) largely due to fossil fuel use (Heard et al., 2017). Given the urgency of mitigation actions, various countries have taken different measures to reduce greenhouse gas (GHG) emissions through Intended Nationally Determined Contributions (INDCs) under the Paris Agreement of 2015 (UNFCCC, 2015). Kenya's INDCs targets a 30% reduction of annual GHG emissions by 2030, compared to business as usual. Investment in renewable energy sources is one of the ways that the government pursues to achieve this (Kenya Power, 2018). However, Kenya faces frequent power outages, an exponential rise in electricity demand, and high energy costs (Mutua, Ngui et al., 2012). The Energy Regulatory Commission (ERC) projects that the power demand will increase by more than 200% by 2030 compared to 2020 (Government of Kenya, 2018).

This chapter investigates Kenya's capacity to supply 100% of its electricity demand with renewable energy resources. It is based on an original questionnaire survey. In the following sections, I first examine past studies on 100% electricity supply with renewable energy sources then introduce the study area for a better understanding of this case study. Finally, I give the case study results and discussion.

3.2 Past studies on 100% electricity supply with renewable energy sources

Globally, several studies have analyzed the feasibility of 100% energy supply with renewables (Blakers et al., 2017; Brown et al., 2018; Duic et al., 2020; Jacobson and Delucchi, 2011; Kroposki et al., 2017). These studies found that countries like Iceland (100%), Paraguay (99%), Norway (97%), Uruguay (95%), Costa Rica (93%), and Brazil (76%) have attained or close to attaining 100% electricity supply with renewables (Kroposki et al., 2017). Besides, some regions and municipalities have already attained 100% renewable supplies, including Germany's

[3] Part of this chapter was presented and published as a conference proceedings paper in the 5th International Conference on Environment and Renewable Energy. Vienna, Austria. May 18-19, 2018. http://environment.scientific-journal.com/articles/7/7.pdf

Mecklenburg-Vorpommern and Schleswig-Holstein, South Island of New Zealand, and the Orkney Islands in Scotland. Small islands like Tokelau, an island in American Samoa, was the first to achieve 100% electricity supply purely by inverter-based solar plus battery systems (Brown et al., 2018).

Several other studies have criticized these proposals advancing different reasons in support of their arguments. First, the insufficient generation capacity to satisfy consumer demand at any given time (Heard et al., 2017). Secondly, proposed solutions are technically feasible but not economically viable (Dalton et al., 2009; Gilbraith et al., 2013). Thirdly, studies relied on unrealistic projections of demand (Heard et al., 2017; Trainer, 2012). Finally, the countries that have currently almost 100% electricity supply rely entirely on stable renewable energy sources like hydro and geothermal while regions like small islands, counties, and towns are too small to be used as feasibility evidence (Heard et al., 2017). With this background, the question is, does Kenya have the capacity to supply the entire electricity and energy demand with renewables?

3.3 Materials and methods

3.3.1 Study areas and data collection

To capture all the areas necessary for renewable energy deployment, I decided to ask those experts in Kenya's energy sector who deal with policy formulation, electricity generation, transmission, and distribution. I contacted those experts who work for technical departments in the Ministry of Energy and Petroleum, semi-autonomous agencies in the state department of energy, independent power producers (IPPs), and research institutions. My respondents from semi-autonomous agencies were drawn from the Energy and Petroleum Regulatory Authority (EPRA), Geothermal Development Company (GDC), Kenya Electricity Generating Company (KenGen), Kenya Electricity Transmission Company (KETRACO), Kenya Power and Lighting Company (KPLC), and the Rural Electrification and Renewable Energy Corporation (REREC).

The data was collected through the questionnaire survey that was administered between May and July 2019. In April 2019, I conducted a preliminary survey with five respondents to ensure that all the questions could be easily understood. Thereafter, I administered a revised multiple-choice questionnaire to 31 respondents through purposive sampling. The collected data were coded and entered into Microsoft Excel 2016. The data were analyzed with Microsoft Excel Analysis ToolPak. Finally, I carried out multiple regression analysis to determine the relationship between the respondents' socio-demographic characteristics and their responses and better understand the implications of my results. The data were summarized using both descriptive and inferential statistics.

3.3.2 Questionnaire design

I formulated the questionnaire after reviewing similar studies on 100% electricity supply with renewables at national, continental and global levels (Aghahosseini et al., 2019; Blakers et al., 2017; Duic et al., 2020; Brown et al., 2018; Jacobson and Delucchi, 2011). I also reviewed studies on renewable energy technical and economic potential (Brown et al., 2016; Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2011) and Kenya's renewable energy potential (Kiplagat et al., 2011). I examined studies that criticized the 100% electricity supply with renewables (Heard et al., 2017; Trainer, 2012, 2013) to understand the main issues of concern. Finally, I reviewed government publications on Kenya's energy planning (Energy Act, 2019; Kenya Power, 2018), generation, and transmission (Government of Kenya, 2013).

I divided the questionnaire into four sections. The first section covered the socio-demographic characteristics of the respondents. The second section focused on the respondents' perception of Kenya's renewable energy economic potential and the capacity to exploit all the renewable energy resources by 2050. The responses would help in clarifying Kenya's economic potential given that currently, only the capacity of technical potential exists. The third section investigated Kenya's capacity to meet its energy demand with renewable energy resources. I asked this question to clarify the adequacy of the available economic potential by comparing it with projected demands for 2030 and 2050 scenarios. In the fourth section, I investigated Kenya's energy policy emphasis and whether it could achieve a 100% energy supply with renewables. Additionally, I looked into specific policies that could be pursued to achieve a 100% electricity supply with renewables. As discussed in chapter 2, energy policies play a crucial role in the growth of renewables. Finally, I asked the respondents what would happen to renewable energy investment when the current feed-in-tariff policy regimes expire. This question would clarify the future of renewables in Kenya as previous researches had indicated a decline or abandoning of investment on renewables upon the expiry if FiTs.

3.4 Results and discussion

3.4.1 Socio-demographic characteristics

The first part of the survey identified age, gender, organization, work experience, and education (Table 3.1). Here I found that about 87% of my respondents were males. About 71% fell within an age bracket of 30-39 years. Only 3% had a diploma (middle-level college) while about 55% had postgraduate qualifications. About 58% of the respondents had between 5 and 10 years of work experience with about 19% over 10 years. They worked for the Ministry of Energy and Petroleum (45%) and the semi-autonomous agencies in the state department of energy (39%). The rest belonged to independent power producers (10%) and research institutions (6%).

3.4.2 Exploitable renewable energy potential

In the second part of the questionnaire survey, I investigated Kenya's renewable energy potential. I asked the respondents that, based on the available technical renewable energy potential, how they rate the economic potential of biomass, geothermal, hydro, and wind renewable energy resources. All the respondents agreed that over 50% of geothermal technical potential is economically exploitable while about 94% and 52% agreed on the same for hydro and wind respectively (Figure 3.1). The least exploitable renewable energy resource economically is biomass with 65% of the respondents indicating that its exploitable potential is less than 50%.

The high exploitable potential of geothermal could be attributed to the concentration of geothermal potential sites in one area (central Rift Valley) and the long experience that Kenya has had in its exploration and exploitation (more than 60 years). The government has also got technical and financial support on feasibility studies, exploration, and exploitation mainly from the World Bank, IMF, and Japan (Boampong and Phillips, 2016). Also, the fact that geothermal is a stable renewable energy source has prompted the government to develop it as the country's baseload thus injecting more financial resources. For example, the government has created Geothermal Development Corporation as a special purpose vehicle (SPV) to undertake geothermal exploration and power generation (Government of Kenya, 2018).

The exploitable potential for hydro could be lower than that of geothermal because about half of the technical potential is categorized as small hydro (Kiplagat et al., 2011). As at now the technology to exploit the small hydro is still very expensive (Eliud et al., 2017). Furthermore, the sites are distributed between the five main drainage areas that are far apart from each other making joint feasibility study and exploitation difficult. The low exploitable potential of wind could be attributed to the high transmission cost as noted by previous studies (Delucchi and Jacobson, 2011). In Kenya, most of the suitable sites for wind power generation are far away from the national grid or the demand centers (Ministry of Energy, 2013). The low economic potential of biomass could be attributed to problems with gathering the biomass resources which are mainly produced by small-scale farmers in rural areas (Kiplagat et al., 2011). A multiple regression analysis on the responses showed no significant relationship between Kenya's renewable energy exploitable potential and the respondents' socio-demographic characteristics.

I then asked the respondents about Kenya's technical capacity to exploit its entire renewable energy resource potential by 2050. Previous researches had shown that the exploitation of renewable energy resources in different countries has been hindered by technical and costs challenges (Jacobson and Delucchi, 2011). About 74% of the respondents indicated that Kenya had a very high or high technical capacity to exploit its entire renewable energy potential in 2050. About 19% indicated average while the rest indicated low. The high technical capacity could be attributed to the fact that Kenya has a long history of investing in all kinds of renewable energy resources. It has received funding and technical support from developed countries (Boampong and Phillips, 2016; Kiplagat et al., 2011).

3.4.3 Renewable energy potential and energy demand

In the third section, I investigated Kenya's capacity to meet its electricity and entire energy demand with renewable energy resources. I asked the respondents to what extent they agreed that Kenya's renewable energy potential could meet electricity and entire energy demand for 2030 and 2050 scenarios. For 2030, about 76% and 45% of the respondents strongly agreed or agreed that Kenya could meet the electricity and entire energy demand respectively with renewables (Figure 3.2). For 2050, a higher percentage of about 89% and 71% of the respondents strongly agreed or agreed that Kenya could meet the electricity and entire energy demand respectively with renewables (Figure 3.2).

These findings are similar to those of Jacobson and Delucchi (Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2011) who found out that the whole world could transition to 100% energy supply from wind, water and solar by 2050. A lower percentage of the respondents agreeing that Kenya would meet its entire energy demand with renewables by 2030 could be attributed to the country's lack of economic capacity to fully exploit its resource potential by 2030 (Government of Kenya, 2018). However, given the recent trends of dropping renewable energy investment costs, the cost of exploiting renewable energy resources could drop drastically by 2050 (Goldstein, 2018)

Multiple regression results showed that experience (p-value=3.898E-02) significantly affected their perception regarding 2030 achievability. Also, gender (p-value=3.621E-02) and organization (p-value=2.541E-03) significantly affected their perception about 2050 achievability. All the respondents with more than 10 years of experience strongly agreed or agreed that Kenya could supply 2030 electricity demand with renewables. On the other hand, about 85% of the male respondents and those working for semi-autonomous agencies in the state department of energy (93%) responded similarly to Kenya's 2050 electricity supply with renewables.

3.4.4 Renewable energy policies

I asked about respondents' opinions on Kenya's energy policies. I also asked the following questions: Does Kenya's energy policy emphasize fossil fuels (FFs) or renewable energy (RE)? Can it achieve a 100% electricity supply with renewable energy sources? Are there any specific policy options that could be implemented if Kenya is to supply its electricity demand with 100% renewable energy sources? Would investment in renewable energy in Kenya continue after the expiry of the current feed-in-tariff (FiTs) regime?

The results showed that about 41% of the respondents strongly agreed or agreed that Kenya's energy policy emphasizes fossil fuels and 53% disagreed. About 88% of the respondents strongly agreed or agreed that Kenya's energy policy emphasizes renewable energy sources. Concerning the second question, about 82% of the respondents strongly agreed or agreed that Kenya's energy policy can achieve a 100% electricity supply with renewable energy sources. A multiple regression analysis of the responses showed no significant relationship between the three issues and the respondents' socio-demographic characteristics.

The higher percentage of the respondents agreeing that Kenya's energy policy emphasizes renewable energy sources could be because, since 2013, the government has focused on electricity generation from renewables. For example, major renewable energy projects like Olkaria IV Geothermal Project (280 MW) in 2015, Lake Turkana Wind Power Project (310MW) in 2018, and many other small and medium-sized renewable energy projects have been commissioned. Additionally, in 2017, the government launched the Kenya Off-grid Solar Access Project

(KOSAP) to improve access in marginalized counties (Kenya Power, 2017; Kenya Power, 2018). This strong focus on generation from renewables could also explain why a higher percentage of respondents agreed that Kenya's policy could achieve a 100% electricity supply with renewables. My multiple regression analysis showed the respondents' education (p-value=4.070E-02) significantly affected their perception of the first question. Most respondents with postgraduate qualifications (71%) disagreed or strongly disagreed.

Secondly, I asked the respondents to what extent they agreed that the different energy policy options effectively promote the adoption of a 100% electricity supply with renewables. The results showed that feed-in-tariffs (94%), zero-rating of import duties on renewable energy technology accessories (84%), investment subsidies (81%), and eliminating subsidies on fossil fuels (71%) were the most viable policies (Figure 3.3). Taxing fossil fuels to reflect its environmental damages (58%) and auctioning (45%) were ranked as the least viable options.

The finding that FiT (94%) is the most viable policy option corresponds with some previous global researches (Schallenberg-rodriguez, 2017) as FiT is one of the most popular investment policies for renewable energy sources. In Kenya, for example, since the implementation of FiT policies in 2008, the investments in all kinds of renewable energy sources has more than tripled (Government of Kenya, 2018). Although the respondents found FiTs very important, multiple regression analysis showed no significant relationship between its viability and the respondents' socio-demographic characteristics.

About 84% of the respondents' found that zero-rating of import duties on renewable energy technology accessories is the second most viable policy option. This result corresponds with other studies (Abdmouleh et al., 2015; George et al., 2019) that found that this policy approach reduces the cost of renewable energy investment making it competitive with fossil fuels. In Kenya, the 2014 amendment to the Value Added Tax (VAT) Act of 2013 exempted import duties and VAT for the construction of electricity generating plants, geothermal exploration, specific renewable energy plants, and machinery. This led to increasing investments in renewable energy technologies by independent power producers as well as commercial and residential consumers (Government of Kenya, 2018).

Another highly viable policy option the respondents selected was renewable energy investment subsidies (81%). Previous studies (Abdmouleh et al., 2015; Timilsina et al., 2012) showed that subsidies incentivized renewable energy development in almost every country. In

India, for example, capital subsidies funded either through donor or government funds were the primary policy driver during the early years of solar development (Timilsina et al., 2012).

I also found that eliminating subsidies for fossil fuels (71%) as a highly viable policy option. This result is supported by previous researches in other regions and countries (Elum, 2017; Shi, 2016). However, phasing out fossil fuel subsidies is politically emotive and needs careful approach (Shi, 2016). Multiple regression showed that gender (p-value=3.588E-03) and experience (p-value=8.491E-03) significantly affected their perception of this option. All the female respondents and most of those with less than five years of experience (86%) strongly agreed or agreed.

Regarding taxing fossil fuels 58% of the respondents agreed. This policy approach aims to make fossil fuel production more expensive and unattractive. Denmark was among the first countries to implement this policy while its introduction in Sweden helped with the expansion of biomass (Abdmouleh et al., 2015). Here, multiple regression analysis found a significant correlation with respondents' gender (p-value=2.542E-03) and experience (p-value=3.664E-06). All the male respondents disagreed or were not sure while 66% of the female respondents strongly agreed or agreed. About 66% of those with more than 10 years of experience strongly agreed or agreed.

Auctioning (45%) could have ranked the lowest policy option according to my respondents as previous studies (Winkler et al., 2018) indicated that its effectiveness would depend on countries and their approaches. Other studies (Haufe and Ehrhart, 2018; Linares, 2014) showed that auctioning has negative past experiences. However, Linares (2014) noted that past negative challenges with auctioning could be mitigated with the appropriate design elements. Multiple regression on the responses with the respondents' socio-economic characteristics showed that organization (p-value=8.097E-03) and experience (p-value=3.600E-02) significantly affected their perception of the viability of auctioning. The majority (83%) of the respondents with more than 10 years of work experience disagreed. Despite 64% of the respondents working with the Ministry of Energy and Petroleum strongly agreeing or agreeing, half of those working with semi-autonomous agencies in state department of energy disagreed.

Finally, I asked the respondents whether investors and electricity consumers would continue investing in renewable energy after the expiry of FiT regimes. About 65% of the respondents found it very likely or likely. This finding differs from some past studies that found that investments on renewables change dramatically with investors either deferring, lowering capital investment, or even withdrawing completely after FiTs (Ritzenhofen and Spinler, 2016). They argue that investors' decision is based on both the tariff size and contract duration of FiTs. For example, when Spain capped its FiT spending after the financial crisis in 2008, there was reduced capacity development, and the government was sued by at least 15 investors (Jenner et al., 2013).

3.5 Summary

This chapter examined the perception of Kenya's energy experts on Kenya's renewable energy exploitable potential and the capacity to supply its electricity and entire energy demand with 100% renewable energy sources. I also investigated Kenya's energy policy emphasis and specific policies that could be implemented to achieve a 100% energy supply from renewables. I found that all the respondents agreed that over 50% of geothermal's technical potential is economically exploitable while about 94% and 52% agreed on the same for hydro and wind respectively. About 76% and 41% of the respondents strongly agreed or agreed that Kenya could meet its electricity and entire energy demand respectively for 2030 with renewable energy resources. All the respondents with more than 10 years of work experience were in this group.

On the other hand, about 89% and 71% strongly agreed or agreed that Kenya could meet its electricity and entire energy demand respectively for 2050 with renewable energy resources. The majority of the male respondents (85%) and those working with semi-autonomous agencies in the state department of energy (93%) were in this group. On energy policy, about 88% of the respondents strongly agreed or agreed that Kenya's energy policy emphasizes renewable energy sources. According to my respondents, the most effective policy options for achieving 100% electricity supply with renewable energy sources are feed-in-tariffs (94%), zero-rating of import duties on renewable energy technology accessories (84%), investment subsidies (81%) and eliminating subsidies on fossil fuels (71%). Another noticeable finding that differs from many current studies is the continued investment in renewables by investors and electricity consumers after the expiry of FiTs. Based on the above findings, I conclude that Kenya has adequate renewable energy resources to meet its electricity and entire energy demand for 2030 and beyond. In the following chapter, I investigate how to address the variability and transmission challenges of 100% electricity supply with renewable energy sources in Kenya's national grid.

Table 3.1 Socio-demographic characteristics of the expert respondents[4]

Characteristics	N	%
Age		
20-29	4	13
30-39	22	71
40-49	3	10
50-59	2	6
Gender		
Male	27	87
Female	4	13
Organization		
Ministry of Energy and Petroleum	14	45
Government Agencies	12	39
Research institutes	2	6
IPPs	3	10
Education Level		
Diploma	1	3
Bachelors’	13	42
Postgraduate	17	55
Work Experience (Years)		
Below 5	7	23
Between 5 and 10	18	58
Over 10	6	19

[4] This table shows the socio-demographic characteristics of the expert respondents where n=31

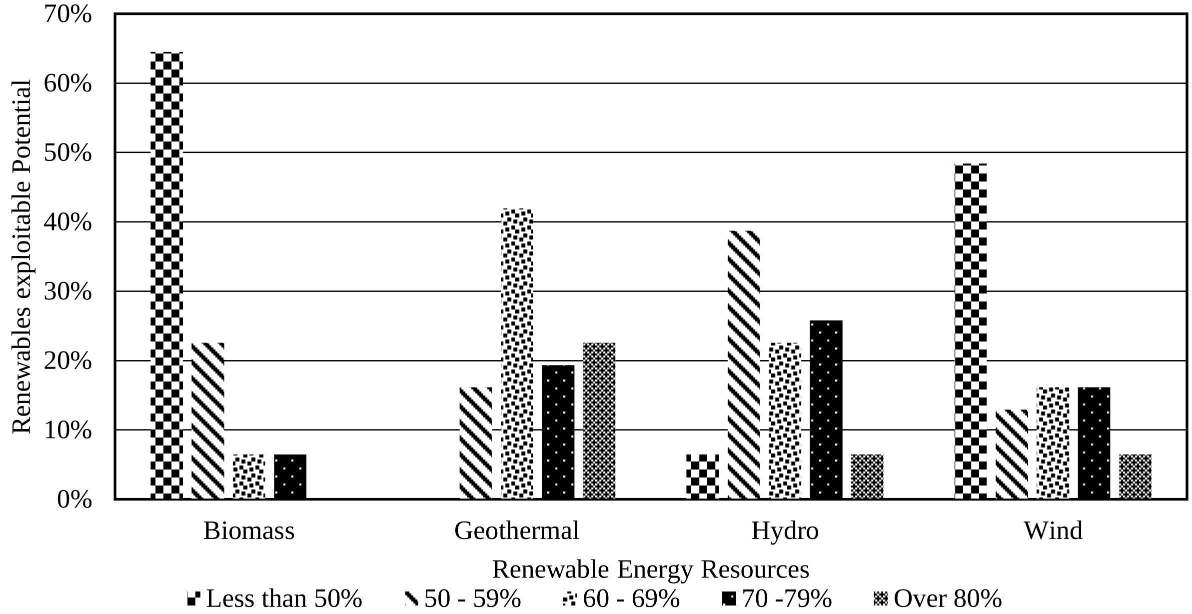

Figure 3.1 Kenya's renewable energy sources economic potential[5]

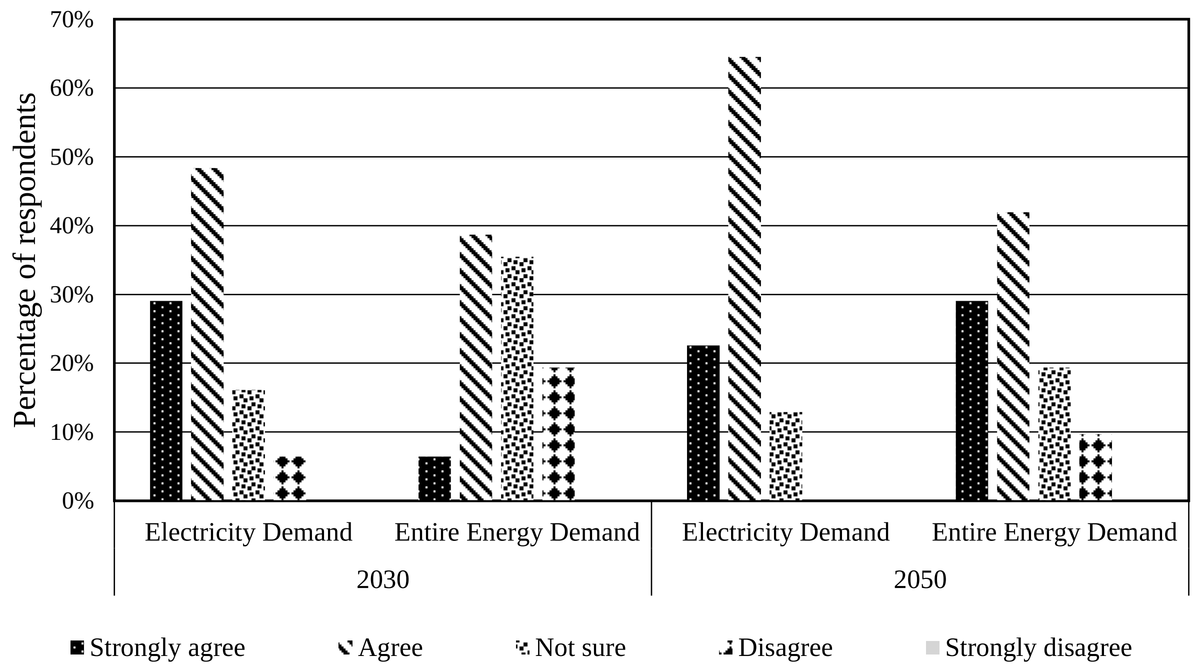

Figure 3.2 Kenya's capacity to meet electricity with renewables in 2030 and 2050

[5] The respondents estimated the economic potential from the existing technical potential

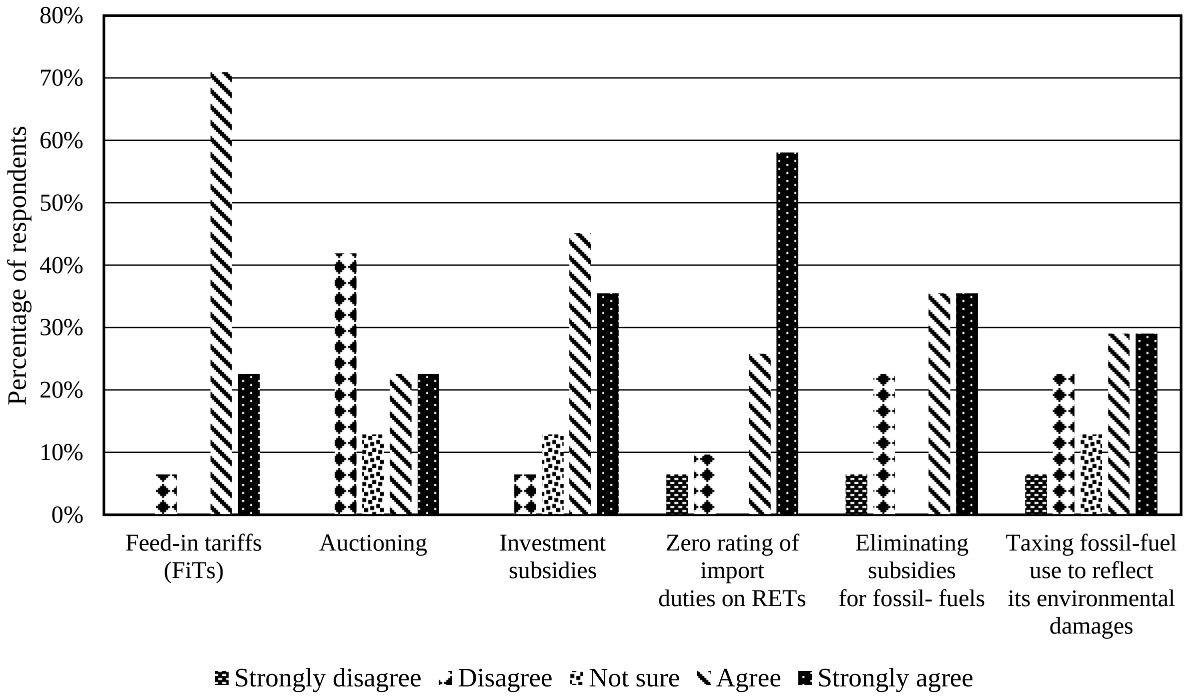

Figure 3.3 Policy viability for achieving 100% electricity supply with renewables[6]

[6] The figure shows the viability of different policies in achieving 100% electricity supply with renewables in Kenya

Chapter 4: Addressing Variability and Transmission Challenges of Electricity Supply with 100% Renewable Energy Sources in Kenya[7]

4.1 Introduction

In Kenya, frequent droughts have rendered the hydroelectric generation unreliable, forcing the government to focus more on geothermal generation (Eberhard et al., 2018). The storage needs for solar PV had limited its use to residential consumers until 2014 when it was connected to the national grid for the first time (Directorate of Electrical Power Development, 2019). The high transmission costs caused a one-year delay on commissioning of Lake Turkana Wind Power Project resulting in losses amounting to US$54 million. Although this project was meant to lower the power cost, it ended up becoming more expensive (Kamau 2017; Fayo, 2018).

Thus, this chapter investigates the variability and transmission challenges of electricity supply with 100% renewable energy sources in Kenya. It is based on an original questionnaire survey. In the following sections, I first examine past studies on variability and transmission of renewables generation then introduce the study area for a better understanding of this case study. Finally, I give the case study results and discussion.

4.2 Past studies on reliability and transmission of renewable energy sources

Previous studies have shown that 100% renewable energy supply is a realistic prospect, while other studies found that it technically achievable (Bac et al., 2016; Connolly et al., 2011; Delucchi and Jacobson, 2011; Hansen et al., 2019). In this regard, a wide variety of technologies and measures are proposed for the transition. Jacobson and Delucchi found that the whole world could be powered with renewables by 2050 (Jacobson and Delucchi, 2011). One of their other study (Jacobson et al., 2017) that looked into 100% renewable energy in 139 countries found multiple solutions for matching peak demand with supply. Another set of studies examined grid stability with renewables in Europe, North-East Asia and Denmark for electricity, heating, and transportation sectors (Bogdanov and Breyer, 2016; Lund et al., 2016; Mathiesen et al., 2015). They found that time-dependent supply can match demand at high penetrations of renewable energy without the need for nuclear power, natural gas, or fossil fuels with carbon capture. In

[7] Part of this chapter was presented at the 5th Edition of EuroSciCon Conference on Environmental Science and Engineering. Budapest, Hungary. October 29-30, 2018

Africa, Barasa et al., (2018) found that a 100% renewable energy system is a reliable solution for sub-Saharan Africa.

Although several studies have shown growing trends towards 100% electricity supply with renewables, other studies argue against it (Heard et al., 2017; Trainer, 2012). Their argument is based on the lack of historical evidence for the feasibility of 100% variable renewable-electricity systems operating at regional or larger scales. Also, they note the lack of attention on the necessary transmission or distribution networks, and the provisions for ancillary services (Heard et al., 2017). They added that the current studies proposing 100% renewable electricity supply do not effectively deal with the challenge of variability (Trainer, 2012). Critics have also claimed that the studies did not take sufficient account of social acceptance constraints and energy consumption beyond the electricity sector (Clack et al., 2017; Trainer, 2012). This chapter, therefore, uses a questionnaire survey administered to energy experts to capture all the aspects of renewables deployment in Kenya.

4.3 Materials and methods

This study targeted experts with first-hand experience and a clear understanding of Kenya's energy sector. These experts worked for the Ministry of Energy and Petroleum, agencies in the state department of energy, independent power producers (IPPs), and research institutions. The agencies' roles include power generation and distribution, rural electrification, geothermal exploration, and regulation of the energy sector. A questionnaire survey was used to collect primary data between May and July 2019. One month before administering the questionnaire, I conducted a preliminary survey among five respondents to make sure that the respondents could understand all the questions. Thereafter, I administered a revised multiple-choice questionnaire to 31 experts through purposive sampling.

The questionnaire was formulated after a literature review on reliability under 100% energy supply with renewables (Connolly et al., 2011; Delucchi and Jacobson, 2011; Hansen, Breyer, et al., 2019; Hansen et al., 2019) and transmission (Herbert and Phimister, 2019). Finally, I reviewed government publications on Kenya's energy planning (Government of Kenya, 2018; Kenya Power, 2016b), generation, and transmission (Kenya Power, 2017; Ministry of Energy and Petroleum, 2013).

The questionnaire was divided into four sections. The first section looked into the socio-demographic characteristics of the respondents. The second section focused on the respondents' perceptions about the suitable methods to deal with variability under a 100% renewable energy supply system in Kenya. Since there are several methods proposed in the literature, I asked this to clarify the specific ones that can be applied in Kenya. The third section investigated the extent to which transmission has affected the deployment of renewable energy sources and the best model to achieve a 100% electricity supply with renewables in Kenya. The responses to this question would provide a clear perspective on the areas that need improvement in preparation for transition to 100% renewable energy supply in Kenya. The fourth section investigated the reliability under 100% electricity supply with renewables. This question sought to clarify if Kenya can reliably supply its electricity demand with renewables. The collected data were coded and entered into Microsoft Excel 2016. The data were analyzed using Microsoft Excel Analysis ToolPak. The data were summarized using both descriptive and inferential statistics.

4.4 Results and discussion

4.4.1 Socio-demographic characteristics

In the first part of the questionnaire, I identified the socio-demographic characteristics of the respondents. I found that about 87% of the respondents were males with 71% falling within the age bracket of 30-39 years. About 97% of them had undergraduate degrees while about 58% had between 5 to 10 years of work experience. A larger percentage of the respondents were from the Ministry of Energy and Petroleum (45%) and the state department of energy (39%). The rest were from independent power producers (10%) and research institutes (6%).

4.4.2 Methods to deal with the reliability of a 100% renewable energy supply system

In the second section, I investigated methods that can be used to address variability and achieve a stable supply of renewable energy. I asked the respondents to rate the viability of various methods of dealing with the variability of renewable energy sources. The results showed that 81% of the respondents rated the use of stable sources like hydro or geothermal to match demand with supply as high or very high. About 61% rated national interconnection as high or very high. About 74% of the respondents rated regional (Eastern Africa Power Pool) interconnection as high or very high. About 13% rated it as average while the rest rated it as low.

These results agree with previous researches which showed that interconnecting geographically dispersed renewable energy sources to a single transmission grid smooths out electricity supply and demand significantly and eliminates hours of zero power (Delucchi & Jacobson, 2011). Another study on powering sub-Sahara with 100% renewable energy sources found that linking the different regions can address the challenge of intermittency in renewable energy technologies (Barasa et al., 2018).

Regarding rural household electricity supply from renewables, about 71% of the respondents rated as high or very high. This corresponds to a study in Australia that found that roof-top mounted solar PV's would supply about 11% of annual electricity consumption (Blakers et al., 2017). Another study in North-East Asia found that prosumers play a key role in achieving a 100% supply from renewables (Bogdanov et al., 2016).

About demand-response management and smart grid, about 68% of the respondents rated as high or very high. Previous researches similarly found that demand-response management allows high penetration of renewables in the grid through load shifting to periods with more renewable energy sources (Delucchi & Jacobson, 2011). This may reduce peak demand. In this regard, a smart grid can provide a platform to implement demand-response management, maximize reliability, availability, efficiency, and higher security from attack and naturally occurring power disruptions (Ellabban & Abu-Rub, 2016).

Regarding the use of micro-grids from renewables, about 61% of the respondents rated as high or very high. The International Energy Agency (IEA) similarly found that 70% of rural areas globally are not suited for grid extension. Instead, renewable energy-powered mini-grids would play a significant role (IEA, 2011). In Kenya, as of 2015, 15 public mini-grids operated by the national utility were almost all diesel-based (Pueyo and Demartino, 2018). However, the government has recognized the importance of renewable mini-grids and started Kenya Off-grid Solar Access Project (KOSAP) targeting the electrification of households (including host communities around the refugee camps), enterprises, community facilities, and water pumps in marginalized areas (Kenya Power, 2017).

Concerning the use of energy storage, about 48% of the respondents rated pumped storage as high or very high. On battery storage, about 39% rated as high or very high. Currently, pumped hydro energy storage (PHES) provides 99% of the world's installed large-scale energy storage capacity (Gaudard and Madani, 2019). However, in Kenya, PHES is limited to a storage capacity of 300 MW located at Suguta Valley at the southern tip of Lake Turkana (Ministry of Energy and Petroleum, 2015).

4.4.3 Transmission

In the third section, I sought to understand the extent to which energy transmission has affected the deployment of renewable energy resources in Kenya. I also asked if fuel cost saving obtained by adopting 100% renewables can be enough to meet the increased transmission cost associated with renewables. Additionally, I wanted to understand the best model to achieve a 100% electricity supply with renewables in Kenya.

First, I asked the respondents to what extent the transmission negatively affected the deployment of renewable energy sources in Kenya. I found that wind power was the most affected with 53% of the respondents indicating that the negative effect was very high or high (Figure 4.1). This was followed by hydro (30%), geothermal (18%), and solar (6%). Previous studies similarly found that wind power generation was vulnerable to transmission costs due to its dispersed locations (Delucchi & Jacobson, 2011).

Secondly, I asked the respondents if they agreed that fuel cost avoidance (thermal power plant) would help meet the transmission costs. The results show that about 76% of the respondents strongly agreed or agreed with it, and about 12% are not sure. Previous research (Delucchi & Jacobson, 2011) similarly found that fossil fuel cost avoidance could help meet the transmission cost.

Finally, I asked the respondents to rate the economic viability of the two transmission systems: extending the national grid or using mini-grids run by renewable energy sources in rural areas. The results showed that about 76% of the respondents rated the mini-grid option as very high or high (Figure 4.2). About 41% rated extending the national grid as very high or high, and 12% as average. Previous researches on a mini-grid option in sub-Saharan Africa (Nkiriki and Ustun, 2017) noted that the deployment of suitable mini-grid systems could increase electricity access cost-effectively.

I conducted a multiple regression analysis to find the correlation between the responses to the two questions with the respondents' socio-demographic characteristics. The results showed that the organization (p-value=1.452E-02) significantly affected their perception of mini-grids. The majority of the respondents who rated this option as high or very high were those working for semi-autonomous agencies in the state department of energy and the MoEP (Government of Kenya, 2018).

4.4.4 Reliability under 100% power supply with renewables

In the fourth section, I asked the respondents how they would rate the reliability of electricity supply in case of attaining a 100% supply with renewables. The result showed that 65% of the respondents rated stability as far better or better than now (Figure 4.3). About 16% rated it the same as now while 13% rated as slightly worse than now. These results show that Kenya has the capacity to reliably supply 100% of its electricity with renewables.

4.5 Summary

This chapter examined the perception of Kenya's energy experts on the country's capacity to overcome the challenges of 100% electricity supply with renewables. It mainly focused on the methods of addressing the variability of renewable energy sources, the influence of transmission, and the reliability under 100% electricity supply with renewables. The results showed that the most viable methods of dealing with variability under 100% renewable energy sources electricity supply are: using non-variable sources to help match demand with supply (81%), regional (74%) and national (61%) interconnection of geographically dispersed renewable energy sources, providing 100% of rural households electricity demand with renewables (71%), applying demand-response management and smart grid (68%) and using micro-grids (61%) run by renewable energy sources.

Currently, the respondents perceive that the deployment of wind power (53%) has been affected the most by transmission. They also rated the use of mini-grids run by renewables (76%) as more economically viable compared to extending the national grid (41%). Another salient finding is that about 65% of the respondents consider the electricity supply stability under 100% as far better than now. Reflecting on these findings, I can conclude that Kenya can overcome the variability and transmission challenges to supply its electricity demand with 100% renewables. In the next chapter, I investigate the future contribution of demand-side management in achieving a 100% electricity supply with renewable energy sources in Kenya.

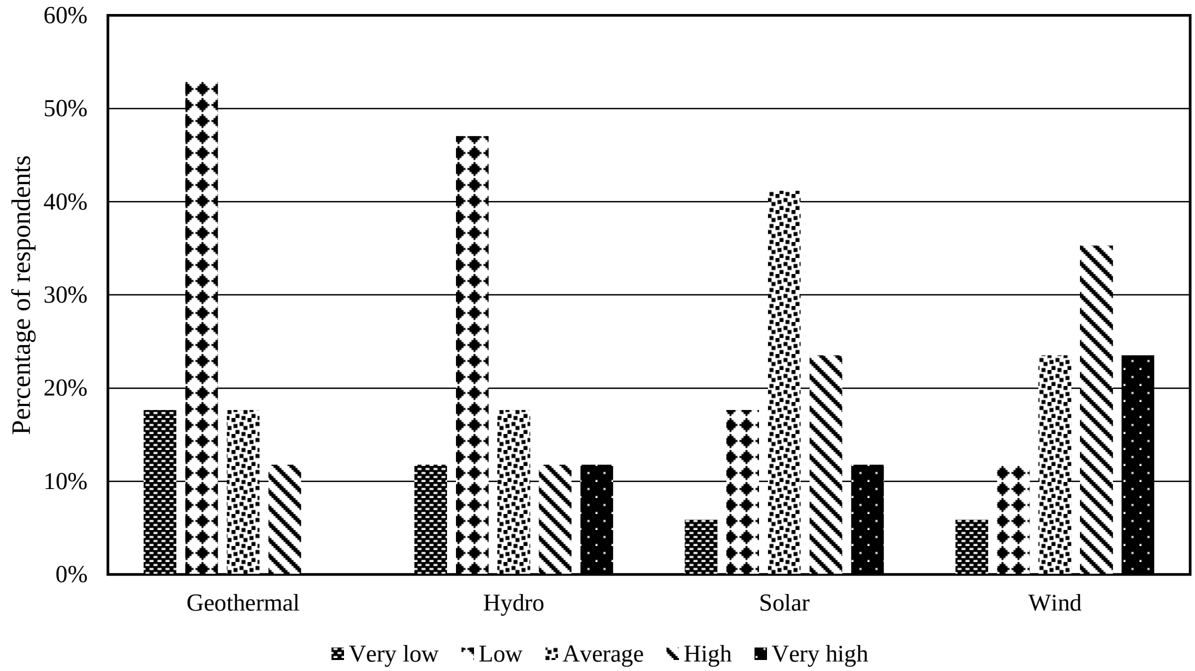

Figure 4.1 The impact of transmission on the deployment of renewables

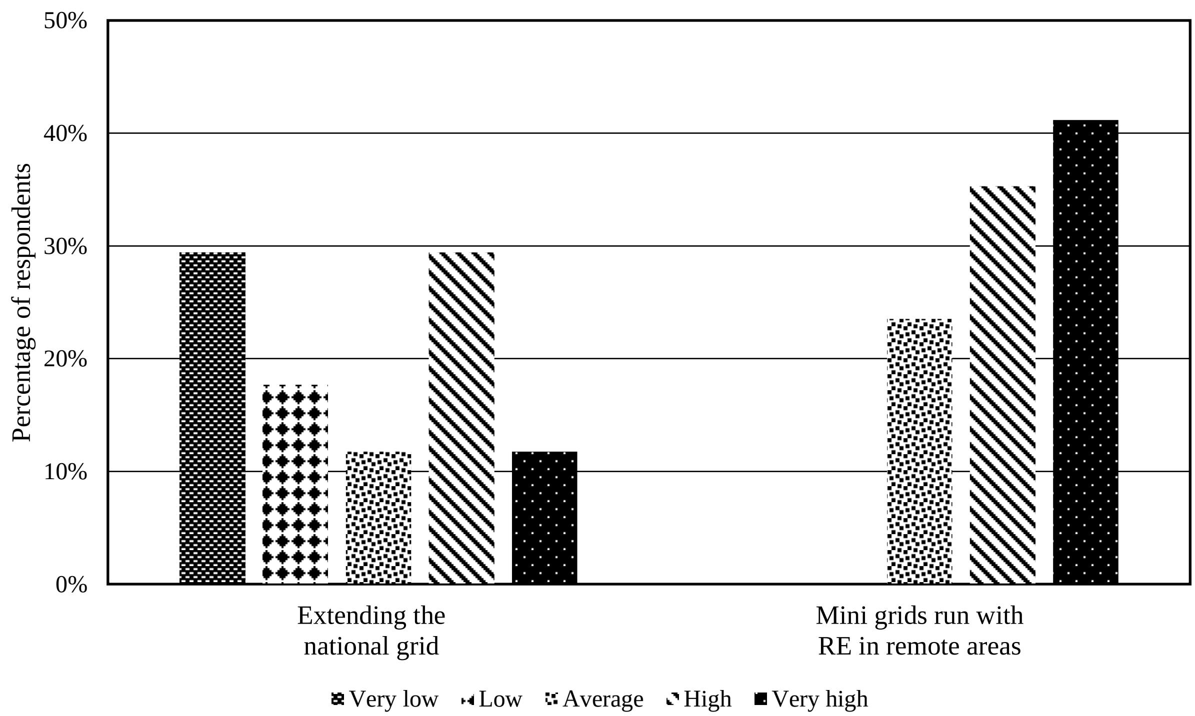

Figure 4.2 Economic viability of transmission options

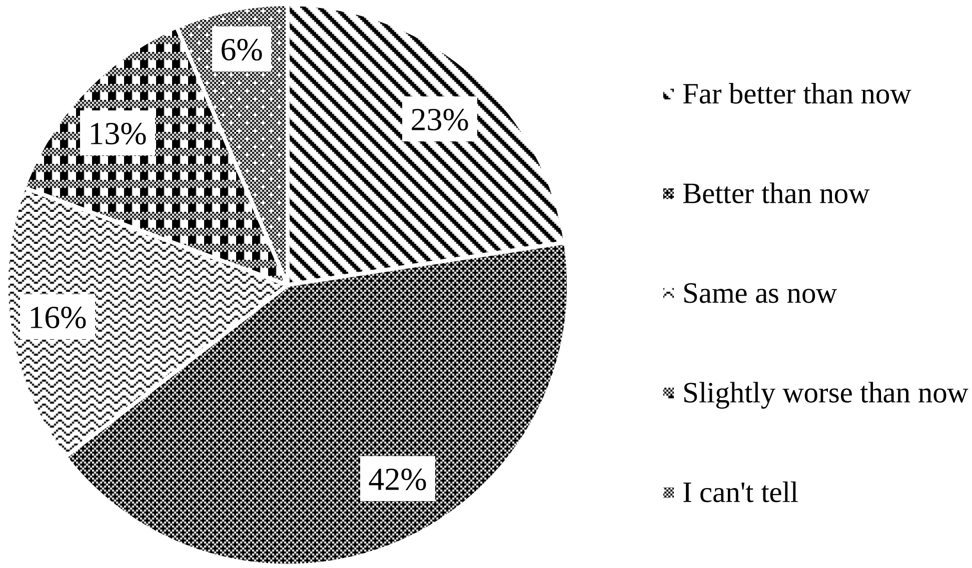

Figure 4.3 Reliability under 100% power supply with renewables

Chapter 5 The Future Contribution of Demand-Side Management in Achieving 100% Electricity Supply with Renewable Energy Sources in Kenya[8]

5.1 Introduction

Kenya's energy sector faces frequent power outages, low access rates in rural areas, low supply capacity, and high transmission/storage losses (Mutua et al., 2012). The Kenya National Economic and Social Council (NESC) intends to achieve a 30% reserve margin as a safety net in dealing with peak demands, but achieving this goal does not yet appear to be realistic. Demand-side management has been proposed as one of the solutions for energy challenges faced by developing countries (Davito et al., 2010; Goulden, 2014; Warren, 2014). It refers to technologies, actions, and programs for consumers to manage energy consumption and contribute to GHG emission reduction (Muratori et al., 2014; Warren, 2014). The availability of smart grid and smart meters have recently allowed residential consumers to also play a vital role in demand-side management (Davito et al., 2010).

This chapter argues that demand-side management has a high potential in balancing and taking full advantage of Kenya's supply capacity. Also, it could be useful in solving energy challenges associated with the expected widespread adoption of intermittent renewable energy sources (Walawalkar et al., 2010). In this perspective, residential consumers have a vital role to play. For example, they could invest in energy-efficient and smart appliances, adopt renewable energy technologies, or shift their consumption to times of low demand. In other words, it is difficult to implement demand-side management programs effectively without the full involvement of residential consumers (Ponce et al., 2016; Mah et al., 2012). Thus, this chapter looks into the future contribution of demand-side management in achieving a 100% electricity supply with renewable energy sources in Kenya. It is based on an original questionnaire survey. In the following sections, I will first examine past studies on demand-side management and then introduce the study area for a better understanding of this case study. Finally, I give the case study results and discussion.

[8] Part of this chapter was published in the *International Journal of Environmental Science and Development,* Vol. 11 No.3, pp. 11-115. March 2020. doi: 10.18178/ijesd.2020.11.3.1235. Also, part of it was presented and published in the conference proceedings of Grand Renewable Energy Japan Council for Renewable Energy. Yokohama, Japan. June 17-22, 2018. https://doi.org/10.24752/gre.1.0_18

5.2 Past studies on demand-side management

Studies in Germany, Italy, Korea, the UK, and the US reiterated the importance of demand-side management (Balta-Ozkan et al., 2014; Davito et al., 2010; Mah et al., 2012; Mah et al., 2014). An analysis of Uganda's energy sector showed that with available technology and best practices, 2,224 GWh can be saved in 2030 across all sectors, representing 31% of the forecasted load. This translates into 341 MW of peak demand reduction (De et al., 2018). In South Africa, the energy storage capabilities of this management showed significant financial savings (53%) among consumers (Longe et al., 2017). In Ethiopia, the energy efficiency aspect of this management showed that it is effective to curb the electricity demand among low-income users with the capacity to reduce electricity consumption by about 45 kWh per consumer (Iimi et al., 2019). A combination of demand-side management strategies reduced 76% of energy consumption in Mali and 56.8% of total daily consumption in Nigeria (Augusto, 2017). Kenya seems to be increasingly interested in demand-side management (KPLC, 2016a).

Studies on this type of management tended to focus on technical aspects without understanding consumers' perceptions (Ellabban & Abu-Rub, 2016; D. N. yin Mah et al., 2012). Some noted difference in consumer behaviors and knowledge between urban and rural areas. These differences, in turn, affected energy demands and perceptions. Different regional attitudes were observed regarding the smart grid and smart homes (Balta-Ozkan et al., 2014). Another study (Ellabban & Abu-Rub, 2016) emphasized the importance of investigating beliefs, knowledge level, and material culture to understand personal choices and energy practices. This chapter attempts to investigate regional contexts of residential electricity consumers' knowledge level and willingness to adopt demand-side management practices in Kenya. I argue that demand side management is the most viable option to manage power demand in Kenya thus facilitating 100% electricity supply with renewables.

5.3 Materials and methods

5.3.1 Study areas and data collection

This study targeted residential electricity consumers. Additionally, I targeted energy experts at the Ministry of Energy and Petroleum, semi-autonomous agencies in the state department of energy, IPPs, and research institutions. In Kenya, urban residents tend to use energy-efficient equipment whereas rural residents tend to use renewable energy sources (Government of Kenya, 2018).

Considering these circumstances and Kenya's topography, climatic conditions, urbanization level, household power demand, and economic activities, I selected Nairobi County (urban), Makueni, and Uasin Gishu counties (rural) (Figure 5.1). The three counties, substantially represent different types of residential energy users in Kenya.

Nairobi County is the most populated in the country. Its population was 4,397,073 in 2019 (KNBS, 2019). Its total surface area is 697 km^2 (KNBS, 2015a). It consumes the largest amount of electricity in the nation (45%) and is projected to remain so over the next 20 years. Makueni County is located about 130 km east of Nairobi (Heap, 2015). It has a total population of 987,653 with sparse distribution, according to the 2019 census (KNBS, 2019). Its total surface area is 6,806 km^2, of which urban areas constitute about 1% (KNBS, 2015b). Some households were beneficiaries of the national efficient lighting program (Kenya Power, 2018). Uasin Gishu County is located about 310 km west of Nairobi (KNBS, 2015c). It has a total population of 1,163,186, which is evenly distributed, according to the 2019 census (KNBS, 2019). Its total surface area is 3,351 km^2, of which urban areas cover about 6%. The County benefited from a World Bank public and street lighting project (Kenya Power, 2018).

The primary data was collected through a questionnaire survey among residential consumers in October and November 2018. In September, a preliminary survey was conducted within all the groups to make sure that the respondents could understand all the questions and avoid anchoring effect given the high frequency of technical terminologies. A revised questionnaire was then administered to 250 household heads through stratified random sampling. I targeted 50 household heads in each county. Considering the diverse socio-economic background of Nairobi County, I targeted 50 residents each from low (Kibera and Mukuru kwa Reuben slums) and middle-high income households (Roysambu, Karen, and Westlands estates). Also, I had 50 respondents from the Nairobi County city center to sample all income levels. The questionnaire was administered mainly during weekends except for shop owners and the Nairobi County city center respondents.

To better understand the national contribution of residential consumers on demand-side management, I administered a questionnaire among 31 experts in Kenya's energy sector through purposive sampling between May and July 2019. Administering questionnaires to experts was also significant since the experts are involved with policy formulation and implementation which are important in integrating demand-side management.

5.3.2 Questionnaire design

The questionnaire design was based on past studies on demand-side management and smart grid (Warren, 2014). I also examined studies on consumer perceptions about demand-side management and smart grid acceptance (Ponce et al., 2016; Mah et al., 2012; Mah et al., 2012)), challenges of adopting demand-side management (Davito et al., 2010), urban and regional energy planning (Iimi et al., 2019; Longe et al., 2017), and Kenya's electricity consumer behaviors (Mutua et al., 2012). I reviewed government policy documents on energy planning and management (KPLC, 2016a; Kenya Power, 2018; Government of Kenya, 2018).

The questionnaire administered to the residential consumers was divided into four sections. The first section attempted to identify the socio-demographic characteristics of the respondents. The second section focused on respondents' level of awareness on smart meters, smart grid, and demand-side management. The level of awareness has a direct impact on the willingness to adopt. The third section attempted to understand their willingness to adopt demand-side management programs. The fourth section looked at the motivations to adopt demand-side management practices. The responses to the last three sections would allow policymakers to determine the best approaches to promote this management option.

The questionnaire administered to the energy experts was divided into two sections. The first section investigated the viability of various demand-side management options while the second section assessed the impact of implementing demand-side management on peak demand. These questions were asked to determine the best options to pursue and obtain maximum benefits from demand-side management. The collected data were coded and entered into Microsoft Excel 2016. The data were analyzed using Microsoft Excel Analysis ToolPak. To understand regional and income level variation in perceptions I conducted ANOVA analysis. Additionally, I carried out multiple regression analyses to understand how consumers' responses varied with their socio-demographic characteristics.

5.4 Results and discussion

5.4.1 Socio-demographic characteristics

In the first part of the questionnaire survey, I asked the respondents about their age, gender, household size, educational level, and monthly income. The results from the residential consumers' respondents showed that about 61% were males (Table 5.1). About 75% of the respondents were within an age bracket of 20-39 years old. Only 3% of the respondents had no formal education and about 89% had at least attained high school education. Among those who had post-secondary education, 60% lived in Nairobi County. About half of those without formal education lived in Uasin Gishu County. About 77% of those with postgraduate education belonged to the middle-high income group in Nairobi County. The household size varied, but about 70% had four or fewer persons. About 63% of the respondents earned a monthly income of between KES10,000 to 50,000 (US$1=KES101.2986 as of January 1, 2018). About 73% of those with less than KES20,000 per month lived in low-income areas of Nairobi County (36%), Makueni County (22%), and Uasin Gishu County (15%).

For the experts, I found that majority (87%) of them were males within an age bracket of 30-39 years (71%). About 55% had postgraduate qualifications while 58% had between 5 and 10 years of work experience with about 19% over 10. About 45% belonged to the Ministry of Energy and Petroleum while 39% belonged to the semi-autonomous agencies in the state department of energy. The rest were from independent power producers (10%) and research institutions (6%).

5.4.2 Consumers' level of awareness on demand-side management

In the second section, I identified the residential consumers' level of awareness on demand-side management and its supporting technologies. I asked the respondents if they were familiar with smart meters, smart grid, and demand-side management. Regarding the familiarity with smart meters, 24% of the respondents were very familiar or familiar, 18% were not sure while 57% were not familiar. Analysis of variance (p-value=2.4465E-09) showed significant statistical differences by regions and social groups. About half (48%) of those who were very familiar or familiar with smart meters belonged to the middle-high income group. About 24% of the respondents in Nairobi County city center were also familiar. The two rural counties and the low-income group in Nairobi County had a lower level of awareness. I observed that some residents in the middle-high income group had installed smart meters.

The multiple regression analysis of these responses in connection with the respondents' socio-demographic characteristics indicates that education (p-value=2.96E-04) and income (p-value=3.8145E-02) significantly affected the level of their familiarity. In short, the more educated and those with higher incomes were more familiar. The low level of awareness on smart meters could be attributed to the fact the utility just started the process of installation with some few consumers. However, this is set to change as research in Europe showed that a large-scale enrollment of smart meters creates a chance to increase consumers' awareness and engagement (Kowalska-Pyzalska, 2018).

On familiarity with the smart grid, similar to the smart meters' results, I found that 20% of the respondents were very familiar or familiar, 21% not sure, and 59% were not familiar. These results agree with those of a similar study in the US that showed that 68% of Americans had never heard about the smart grid in 2010 (Ellabban and Abu-Rub, 2016). Another survey in the US in 2011 found that only 41% of the consumers were familiar with the smart grid. An analysis of variance (p-value=1.16E-10) shows that those of my respondents who were very familiar or familiar with the smart grid mainly belonged to the middle-high income group (44%) and Nairobi County city center group (24%). The multiple regression analysis indicates that income (p-value=2.2924E-02) significantly affected the level of their familiarity.

Regarding familiarity with demand-side management, about 43% of the respondents were very familiar or familiar, 15% not sure, and 42% not familiar. Similarly, previous researches in Ghana and Uganda found that residential consumers were not informed about the possibilities and opportunities of demand-side management (Agyarko et al., 2020). An analysis of variance (p-value=6.11E-05) (Table 5.2) shows that 48% of the middle-high income group, 44% of the city center, and 42% of the low-income respondents were very familiar or familiar. The familiarity among the respondents in Uasin Gishu and Makueni were 40% and 38%, respectively. The high level of familiarity on demand-side management compared to its supporting technologies could be attributed to the fact that some programs like the use of energy-efficient equipment and application of renewable energy technologies are already being conducted in the three counties (Kenya Power, 2018). The multiple regression analysis of these responses in connection to the respondents' socio-demographic characteristics indicates that income (p-value=4.40E-02) significantly affected the level of their familiarity (Table 5.3).

Following this question, I asked those respondents' who were very familiar or familiar with smart meters, smart grid, and demand-side management how they obtained the knowledge. Some received information from radio/TV (35%) and school/internet (28%). Another significant percentage mentioned social media (23%) and newspapers (10%). Only 4% attributed their source of information to training by the power distribution company (KPLC) and the regulator (EPRA).

These findings agree with a study in Ghana that found that mass media serves as a crucial avenue for raising electricity consumers' awareness on demand-side management (Agyarko et al., 2020).

Regionally, most of those who receive information from radio/TV are from the rural counties of Uasin Gishu (61%) and Makueni (50%) and the low-income category (41%). Most of those who receive information from school/internet were those in Nairobi County city center (47%) and middle-high income (31%) groups. Social media is mainly used as a source of information by the respondents in Nairobi County city center (35%), low-income (28%), and the high-income (22%) groups. The rural counties of Uasin Gishu (17%) and Makueni (12%) use it to a lesser extent. This can be attributed to the fact that literacy level, internet penetration and the use of smartphones is higher in Nairobi County than the other counties of Kenya.

The majority of those who used newspapers belonged to the middle and high-income groups (28%). This can be attributed to the fact that most of those who purchase newspapers are the middle and high-income category. They worked for the government or companies where they could have daily access to newspapers. Interestingly, all those who received information from KPLC/EPRA were from Makueni County. This could be as a result of training provided to locals during the construction of the solar power mini-grid in the area (Heap, 2015). These findings indicate the most suitable channels for consumer education and raising their level of awareness on demand-side management and its benefits. Although the government has been trying to educate the residential consumers, the findings indicate that this has not been very successful especially in the rural areas (Government of Kenya, 2018).

5.4.3 Willingness to adopt demand-side management practices

In the third section, I investigated residential electricity consumers' willingness to adopt demand-side management practices. First, I asked the respondents about their willingness to shift their daily electricity usage period from peak hours to lower-demand hours. I found that about 48% of the respondents were willing to do so permanently, whereas another 40% showed their willingness on an occasional basis. Only 12% was negative. These findings agree with a similar survey among consumers in Hong Kong that indicated a high level of willingness to shift consumption period (84.1%) (D. N. yin Mah et al., 2012). This is very vital as Kenya tries to reduce the peak demand occurring between 18:30 and 22:30 resulting in frequent power outages (Government of Kenya, 2018).

ANOVA analysis (p-value=4.794E-05) showed regional and income-level differences (Table 5.4). In Uasin Gishu and Makeuni, 62% and 56% of the respondents were positive. In Nairobi County, 44% of the low-income respondents expressed their willingness. Those who were willing to shift their electricity use hours to off the peak period sometimes belonged to the middle-high income group (54%) and the low-income group (50%). In the city center of Nairobi County, 42% did not wish to shift. The majority of those in the rural counties could be willing to shift consumption since they had installed solar PV as an alternative source of energy.

The multiple regression analysis of these responses in connection with the respondents' socio-demographic characteristics indicated that gender (p-value=5E-02) significantly affected their willingness to shift (Table 5.5). Female respondents were more willing to do so.

With about half (48%) of the respondents willing to always shift their consumption from peak hours to lower-demand hours and another 40% willing to shift sometimes, it provides a unique opportunity to lower the peak demand. This could help reduce the power outages associated with peak demand between 18:30 and 22:30. Consumers could be encouraged to shift their consumption through price responsive demand. This will also allow the deployment of variable renewable energy sources in the national grid by encouraging consumers to shift their demand to periods of strong wind or sun. It could be achieved through modernizing the national grid and fast-tracking the installation of smart meters to support real-time communication with the consumers. This will support the consumers' decision making based on the information that comes from it (Kenya Power, 2018).

Following this question, I asked the respondents about their willingness to adopt the following programs: (1) a smartphone application that displays electricity consumption, (2) a smartphone application that allows electricity payment from their bank/M-Pesa accounts, and (3) in-home displays (IHDs) that give the next electricity bill projection. M-Pesa allows money transfer through a mobile phone. This service is offered by Safaricom, the largest mobile network provider in Kenya.

I found that about 95% of the respondents either strongly agreed or agreed to have the first option, a consumption display application. About the second option for on-line payment, 87% either strongly agreed or agreed. Regarding the third one, 81% strongly agreed or agreed to have a function on the IHDs.

Analysis of variance showed that 82% of those in Makueni and 72% in Uasin Gishu strongly agreed to have the second option. For these rural residents with a sparse population, M-Pesa is readily available whereas bank branch offices are often far away in distance. The middle-high income respondents (72%) and those in the city center (58%) preferred the third option. In Nairobi County, electricity consumption is higher than in other areas (Government of Kenya, 2018). Multiple regression analysis showed that education (p-value=4.2371E-02) significantly affected their choice of a mobile application. Also, more educated respondents strongly agreed to have a mobile application displaying consumption.

5.4.4 Motivation to adopt demand-side management practices

In the fourth section, I asked the residential consumers' respondents about their motivation to adopt demand-side management practices (e.g., smart meters, IHDs). For this, I gave four options for the respondents to choose from (multiple choice).

The results showed that the respondents were largely motivated by energy cost saving (65%), environmental concerns (17%), technological curiosity (12%), and information gathering (5%) (Figure 5.2). Geographically, energy cost saving was an important factor for the respondents in Nairobi County's low-income group (86%), the city center (66%), and the middle-high income group (62%). Environmental concerns were important among those in the middle-high income group (36%) and Makueni County (26%). Technological curiosity also interested some of the respondents in Uasin Gishu (30%) and Makueni (16%). Similar studies in the US show that consumers are more concerned with cost-saving (81%). This is more so in Kenya where consumers experience a very high cost of power coupled with frequent outages (Boampong & Phillips, 2016; Mutua et al., 2012). Environmental concerns could have ranked lower as previous studies have shown that consumers do not fully equate electricity usage with its environmental impact (Ellabban & Abu-Rub, 2016).

5.4.5 The viability of various demand-side management practices

For the expert respondents, I asked them to rate the viability of the different demand-side management options. The results showed that the most viable options for the respondents were price-responsive demand (81%), household renewable energy adoption (74%), energy efficiency and conservation (64%), and integration of smart appliances (61%) (Figure 5.3).

My respondents' ranking of price-responsive demand as the most viable option is similar to some previous researches in the US and Europe (Davito et al., 2010; Märkle-huß et al., 2018). A US study found that a peak demand reduction of 5% could reduce the peak demand by about 50% (Spees and Lave, 2008). Price-responsive demand is more significant for Kenya where the peak demand was about 12% of installed capacity in 2018 (Kenya Power, 2018). My multiple regression analysis showed that price-responsive energy demand had significant correlations with gender (p-value=1.807E-03) and education (p-value=3.559E-02). Most of the male respondents (89%) and those with a postgraduate degree (95%) tended to rate this option as high or very high.

Regarding household renewable energy adoption as the second most viable option, the multiple regression analysis showed that the viability of household renewable energy adoption had significant correlations with age (p-value=2.346E-03), education (p-value=3.080E-06) and experience (p-value=4.471E-04). Those who responded high or very high were 30-39 years old (69%). Also, most of those with a bachelor's degree (85%) and those with more than 10 years of work experience (83%) chose this option.

On energy efficiency and conservation, my multiple regression analysis showed a significant connection between energy efficiency/conservation and respondents' gender (p-value=2.353E-02) and education (p-value=2.470E-02). The majority of male respondents (74%) and those with postgraduate degrees (95%) indicated high or very high. As for the integration of smart appliances, although the respondents found important (61%), the multiple regression analysis showed no significant relationship between the viability of integrating smart appliances and the respondents' socio-demographic characteristics. Although smart metering and distribution automation ranked the lowest (54%), the multiple regression analysis found the significant connection between this option and respondents' organization (p-value=1.683E-02). The majority of those working for government institutions rated this option high or very high. This could be because Kenya has started installing smart meters and adopting grid modernization (KPLC, 2016a; Government of Kenya, 2018).

5.4.6 Impact of demand-side management implementation on peak demand

I also asked the experts the extent to which the peak demand would be reduced by implementing the various demand-side management programs. In response, about 48% indicated that the peak demand would be reduced by more than 50%. Another 23% said that it would be reduced by 40 to

49%. This result corresponds with the findings of the studies in Europe and the US (Davito et al., 2010). For example, the US Federal Energy Regulatory Commission estimated that demand-side management could potentially reduce as much as 150 GW in the 2019 peak energy period, compared to the business-as-usual scenario. As a typical peaking power plant produces about 75 MW, this reduction is equivalent to the output of about 2,000 such power plants (Federal Regulatory Commission, 2009).

Here the multiple regression analysis showed significant connection between the impact of demand-side management implementation and respondents' age (p-value=2.942E-05), experience (p-value=4.848E-04) and education (p-value=5.85E-08). About 76% of the respondents who were 20 to 39 years old tended to believe the reduction rate to be more than 40%. Those with postgraduate degrees (84%) and with less than 10 years of work experience (78%) indicated the same.

5.5 Summary

This chapter examined Kenya's residential electricity consumers' awareness, willingness and motivation to adopt demand-side management. I also investigated the most viable demand-side management options and the impact of implementing the various options on the peak demand through questionnaire administered to energy experts in Kenya. I found a low level of familiarity with a smart meter (24%), the smart grid (20%), and demand-side management (43%) among the respondents. The majority of the familiar respondents were from Nairobi County (urban). However, to avoid power outages during peak hours, 48% of the respondents expressed their willingness to shift the period they use electricity permanently, whereas another 40% would do so sometimes. The majority of these respondents were from the rural counties of Makueni and Uasin Gishu. The main motivating factors for them to practice demand-side management were to save energy costs (65%) and environmental conservation (17%). Generally, urban respondents were motivated by cost-saving while the rural area respondents were motivated by environmental conservation.

The energy expert respondents indicated that price-responsive demand (81%), renewable energy adoption by households (74%), energy efficiency and conservation (64%), and integration of smart appliances (61%) were the most viable demand-side management options for Kenya. By implementing some of these demand-side management practices, about 48% of the respondents, mostly with postgraduate degrees, said that the peak demand would be reduced by over 50%.

Although Kenya’s residential electricity users do not have a high level of awareness on demand-side management options, the results clearly show that the majority are willing to adopt more of these management options. This investigation on Kenya’s residential electricity consumers’ behaviors and practices will shed light on the complex outlook of the regional energy demand matrix. I argue that Kenya can enhance the effectiveness and efficiency of its implementation efforts for demand-side management by reflecting more on regional needs and household motivations. In conclusion, by incorporating regional needs and motivations in the implementation efforts of demand-side management policies, Kenya can achieve its vision of 100% electricity supply from renewable energy sources more effectively. In the next chapter, I will investigate the residential consumers’ willingness to supply their entire electricity demand with renewable energy sources in Kenya.

Table 5.1 Socio-demographic characteristics of the respondents[9]

Characteristics	N	%
Age		
Under 20	7	3
20–29	126	50
30–39	63	25
40–49	39	16
50–59	12	5
60 and above	3	1
Gender		
Male	152	61
Female	98	39
Household size		
1–2	73	29
3–4	103	41
5–6	61	25
7–8	11	4
9–10	1	0.4
Over 10	1	0.4
Education Level		
No formal education	8	3
Primary	20	8
Secondary	75	30
Diploma	71	29
Bachelors'	63	25
Postgraduate	13	5
Monthly income (KES)		
Less than 10,000	38	15
10,000–20,000	81	32
20,001–50,000	77	31
50,001–80,000	23	9
80,001–100,000	8	3
100,001–150,000	9	4
150,001–200,000	7	3
Over 200,000	7	3

[9] The table shows the socio-demographic characteristics of the respondents in the three counties of Makueni, Nairobi and Uasin Gishu (n=250)

Table 5.2 ANOVA analysis on the level of awareness on demand-side management[10]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	40.704	4	10.176	6.436	6.110E-05	2.408
Within Groups	387.360	245	1.581			
Total	428.064	249				

Table 5.3 Multiple regression analysis of the level of awareness on demand-side management[11]

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.868	0.483	8.012	0.000	2.917	4.819
Age	-0.034	0.090	-0.374	0.709	-0.211	0.144
Gender	-0.111	0.168	-0.661	0.509	-0.443	0.220
Household size	0.069	0.095	0.718	0.473	-0.120	0.257
Income	0.118	0.058	-2.023	0.044	-0.232	-0.003
Education	-0.088	0.079	-1.122	0.263	-0.243	0.067

[10] This table shows the analysis of variance on the respondents' level of awareness on demand-side management between the three counties
[11] This table shows the results of multiple regression analysis of age, gender, household size, income and education against the respondents' level of awareness on demand-side management

Table 5.4 ANOVA analysis on the willingness to adopt demand-side management practices[12]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.576	4	2.894	6.581	4.794E-05	2.408
Within Groups	107.740	245	0.439			
Total	119.316	249				

Table 5.5 Multiple regression analysis of willingness to adopt demand-side management[13]

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.084	0.253	8.221	0.000	1.584	2.583
Age	-0.055	0.047	-1.154	0.250	-0.148	0.039
Gender	-0.174	0.088	-1.970	0.050	-0.348	0.000
Household size	-0.052	0.050	-1.035	0.302	-0.151	0.047
Income	-0.044	0.031	-1.428	0.155	-0.104	0.017
Education	0.051	0.041	1.230	0.220	-0.031	0.132

[12] This table shows the analysis of variance on the respondents' willingness to adopt demand-side management practices

[13] This table shows the results of multiple regression analysis of age, gender, household size, income and education against the respondents' willingness to adopt demand-side management

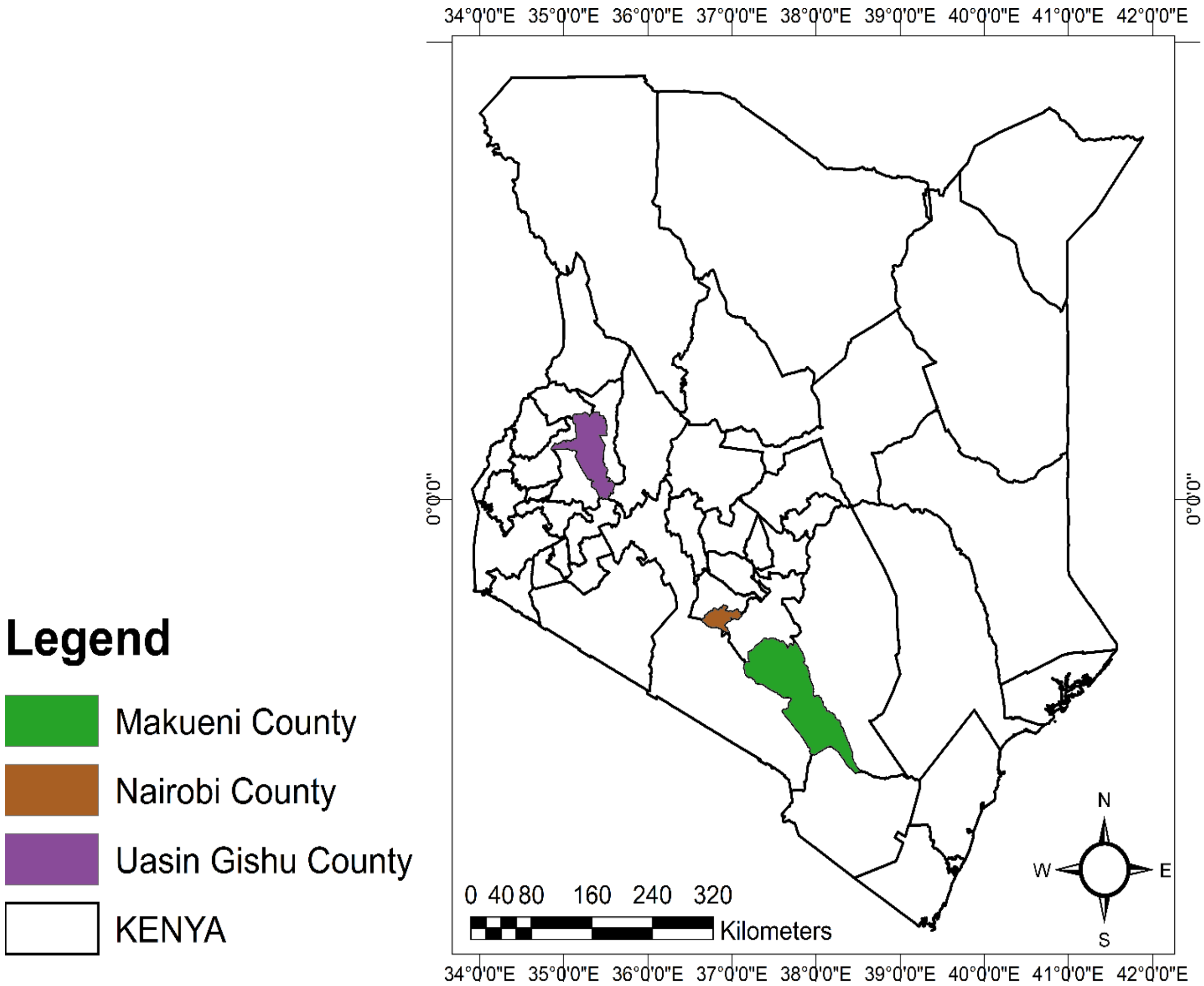

Figure 5.1 Map showing the study areas

Source: KNBS, 2019

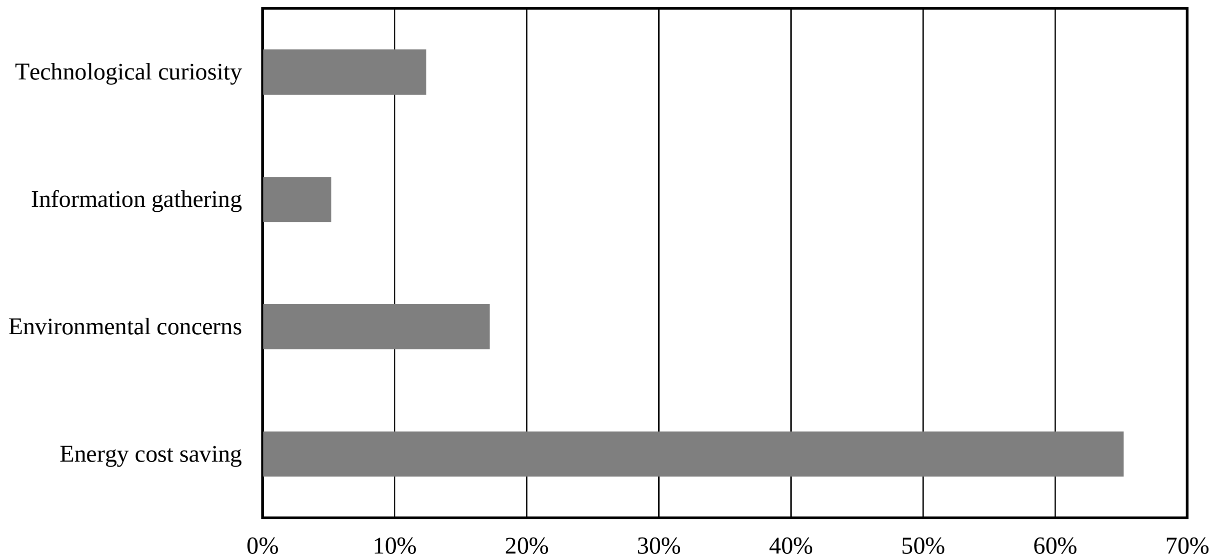

Figure 5.2 Motivation to adopt demand-side management practices[14]

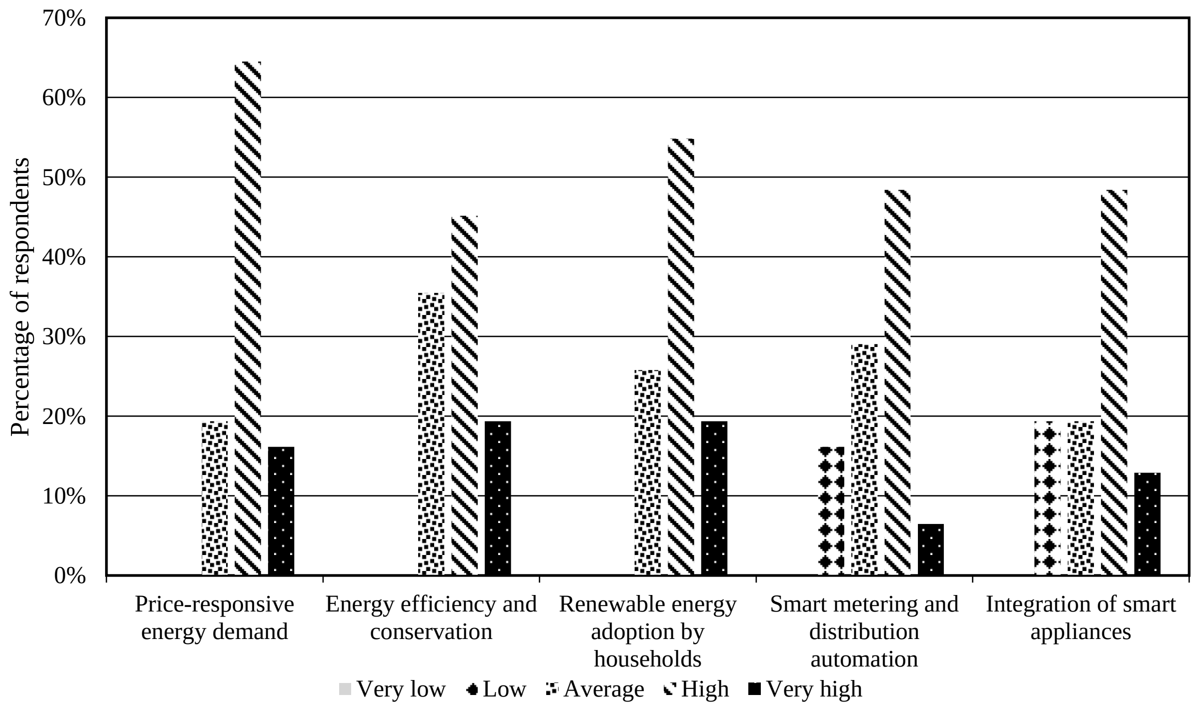

Figure 5.3 Most viable demand-side management practices in Kenya[15]

[14] This figure shows the consumer respondents' motivation to adopt demand-side management (n=250)
[15] This figure shows the expert respondents' perception on the most viable demand-side management practices in Kenya (n=31)

Chapter 6 Residential Consumers' Willingness to Adopt Renewable Energy Sources[16]

6.1 Introduction

Residential energy consumption reduction can play a significant role in mitigating climate change (Azizalrahman & Hasyimi, 2019). Residential emissions particularly from urban areas account for 30%–40% of the global greenhouse gases (GHGs) emission (Nejat et al. , 2015). In Kenya, since 2012, residential energy consumption has grown by 28%. This growth occurred mainly as a result of urbanization and improved electricity access in rural areas (Government of Kenya, 2018). Currently, residential use accounts for 31% of the total electricity consumption (KPLC, 2017). In 2018, hoping to dramatically change this energy consumption outlook, the Kenyan government announced that it would supply 100% of its energy from renewable resources. However, it has not put in place an elaborate plan.

In this chapter, I argue that residential consumers will play a crucial role in achieving a 100% electricity supply with renewables. However, until now, the question remains as to the extent to which residential energy consumers are willing to adopt renewable energy technologies in developing countries like Kenya that has suffered from chronic poverty conditions but is endowed with a high renewable energy generation potential. Currently, however, only about 1.2% of Kenyan households have installed home solar systems. Some communities have undertaken community-level hydro projects while other individuals have invested in wind power generation (Government of Kenya, 2018).

6.2 Past studies on consumer willingness to adopt renewable energy sources

In an international context, studies found that consumers' decisions to adopt renewable energy technologies were influenced by motivational, contextual, and habitual factors (Kowalska-Pyzalska, 2018). Some studies emphasized that residents adopted renewable energy technologies because of prospects for economic benefits or social pressure from their peers and neighbors (Kowalska-Pyzalska, 2018; Palmer et al., 2015). Others suggested that environmental motivations induced people to adopt renewable energy (Palmer et al., 2015). Some research found a strong link

[16] Part of this chapter was published in the *Journal of Environments,* Vol. 6 No. 8. August 2019. https://doi.org/10.3390/environments6080095

between household environmental attitudes, energy consumption, and investment patterns (Masini and Menichetti, 2012). Government incentives would also induce the adoption of renewable energy as the cost appears to be a strong barrier to adoption (Kowalska-Pyzalska, 2018; Masini and Menichetti, 2012; Musall and Kuik, 2011).

Previous studies (Baharoon et al., 2016; Balta-Ozkan et al., 2015) also demonstrated that consumer perceptions about renewable energy often vary by country. Even within a country studies (Balta-Ozkan & Le Gallo, 2018; Hori, Kondo, Nogata, & Ben, 2013) showed that those in rural areas are more likely to invest in renewable energy than those in urban areas. Other studies (Bawakyillenuo, 2012; Tabakovic et al., 2017) noted that different lifestyles affect technological choices. To grow the building-integrated photovoltaics (BIPV) market, the education of urban residential consumers is crucial (Tabakovic et al., 2017). These studies nevertheless have paid scant attention to residential consumers' attitudes and willingness to adopt renewable energy in Kenya.

6.3 Materials and methods

This study targets both urban and rural residential electricity consumers. I selected the urban county of Nairobi and the largely rural counties of Makueni and Uasin Gishu. These counties have differences in electricity access rates, population distribution, electricity usage, and climatic conditions. The government has focused on renewable energy projects for rural areas (Bawakyillenuo, 2012) as grid extension has progressed relatively slowly in these areas. The eastern part of the capital city generally receives less rainfall than the western part does. The three counties, therefore, are a good representation of urban and rural areas in Kenya.

Nairobi County is Kenya's capital. It receives an average annual precipitation of 926 mm with annual average maximum and minimum daily temperatures of 25.3°C and 12.6°C, respectively (KNBS, 2015a). Nairobi County has benefitted from the World Bank-funded project of public/street lighting program (Kenya Power, 2018). Also, it was the main beneficiary of the slum electrification project (Kenya Power, 2016a). Demographically, Nairobi residents can be classified as low, middle-high-income groups by residential areas (KNBS, 2015). The main economic activities are manufacturing, tourism, commercial, and financial services. The average annual photovoltaic (PV) electricity output is 1530 kWh/kWp. The average annual wind power density ranges from poor to marginal (0–165 w/m^2) although some spots are very good (425–615 w/m^2) (Theuri, 2008; Ministry of Energy, 2013). The County has no known hydropower generation potential (Ministry of Energy and Petroleum, 2015).

Makueni County is one of the semi-arid counties. It is located in eastern Kenya (Heap, 2015). It receives an average annual precipitation of 596 mm with an annual average maximum and minimum temperatures of 28.2°C and 16.8°C, respectively (KNBS, 2015b). To increase electricity access in rural areas, in 2012, the government set up a 13.5 kWp solar plant, battery storage, and canopy at the Kitonyoni village trading center. This solar project supplies electricity to about 3,000 residents (Heap, 2015). The main economic activities here are agriculture (especially animal husbandry) and commerce. The average annual photovoltaic electricity output is 1573 kWh/kWp. The average annual wind power density ranges from poor to marginal (0–165 w/m^2), although some spots are classified as good (275–425 w/m^2) (Theuri, 2008; Ministry of Energy, 2013). Given the arid and semi-arid nature of the County, it has little hydropower generation potential (Ministry of Energy and Petroleum, 2015).

Uasin Gishu County is located on a plateau in western Kenya (KNBS, 2015). It receives an average annual precipitation of 1100 mm with an annual average maximum and minimum temperatures of 23.3°C and 11.3°C, respectively (KNBS, 2015c). The average annual photovoltaic electricity output is 1793 kWh/kWp, while the average annual wind power density ranges from poor to marginal (0–165 w/m^2) with some high-density spots (275–425 w/m^2) (Theuri, 2008; Ministry of Energy, 2013). This County also has the potential for small hydroelectric generation and is one of the main catchment areas of Lake Victoria (Kiplagat et al., 2011; Ministry of Energy and Petroleum, 2015). It benefited from a World Bank-funded project of public/street lighting program (Kenya Power, 2018).

To collect primary data, I administered a questionnaire survey between October and November 2018. In September, I carried out a preliminary survey then administered a revised questionnaire to 250 household heads through random sampling in the three counties of Nairobi, Makueni, and Uasin Gishu. I targeted 50 household heads in each county evenly distributed to cover different parts of the county according to the local conditions. Given the high population and diversity of Nairobi County, I obtained cooperation from 100 residents from both low-income households and middle-high-income households, and 50 respondents from the city center.

The questionnaire was formulated after reviewing similar studies on consumers' perceptions of renewable energy (Abdmouleh et al., 2018; Balta-Ozkan and Le Gallo, 2018;

Kowalska-Pyzalska, 2018), renewable energy acceptance and policies (Musall and Kuik, 2011; Sommerfeld et al., 2017), and specific renewable energy technology studies (Pickett-Baker, 2008). Additionally, an extensive review of government publications on rural and urban electrification projects (Kenya Power, 2018), energy generation and transmission (Government of Kenya, 2013), energy planning (KPLC, 2017), and reports on energy generation and supply (Kenya Power, 2016b) was carried out.

The questionnaire was divided into six sections. In the first section, I attempted to determine the socio-demographic characteristics of the respondents, including the current source of electricity. The second section focused on respondents' concerns about environmental conservation, air pollution associated with diesel power generation plants, and the types of power they used. The third section investigated their willingness to accept 100% of their power supply from renewable energy sources, and their perceptions about government support for this purpose. The fourth section attempted to find out what renewable energy technologies the respondents would be willing to adopt and invest in. The fifth section looked into the motivations to invest in renewable energy technologies. The sixth section assessed the challenges residents faced in installing renewable energy technologies. The responses to sections five and six are useful in determining the type of support that can be extended to consumers. The collected data were coded and entered into Microsoft Excel 2016. The data were analyzed using Microsoft Excel Analysis ToolPak. The data were summarized using both descriptive and inferential statistics. Additionally, analysis of variance (ANOVA) was carried out to understand regional and income level variation in perceptions. Finally, I carried out multiple regression analyses to understand how consumers' responses varied with their socio-demographic characteristics.

6.4 Results and discussions

6.4.1 Socio-demographic characteristics

The first part of the questionnaire on socio-demographic characteristics identified age, gender, household size, educational level, and monthly income. Additionally, I asked the respondents to state their current electricity source. Here I found that about 61% of the respondents were males. Three-quarters of the respondents fell within an age bracket of 20–39 years old. Only 3% of the respondents had no formal education and 89% had at least attained high school education. About 77% of those with postgraduate qualifications were from the middle and high-income category in

Nairobi County. Those in Uasin Gishu, a rural county, tended to be less educated. Regarding household size, 70% had four or fewer persons. Those who had more than five persons tended to be in Uasin Gishu County (39%).

On the question of their current electric power source, about 74% of the respondents obtained their electricity solely from the national grid, while 16% did from the combined sources of the national grid and solar PV. About 7% had electricity from a solar mini-grid, while 3% had all their electricity supplies from household solar PV with battery. All the respondents in Nairobi County were connected to the national grid. Those who used electricity from both the national grid and solar PV were mainly from Uasin Gishu (48%) and Makueni (32%). All those who received power from a solar mini-grid were from Makueni County. Three-quarters of the households who had all their electricity from household solar PV with the battery were from Makueni County while the rest were from Uasin Gishu County.

6.4.2 Concern on environment and power generation

In the second section, I asked the respondents about the extent to which they cared about (1) environmental conservation, (2) air pollution associated with diesel power generation, and (3) the type of power sources they used (renewable or non-renewable sources). The results show that about 98% of the respondents either strongly cared about or cared about environmental conservation. Similarly, about 96% either strongly cared or cared about air pollution that was associated with diesel power generation. About 84% of the respondents strongly cared or cared whether the energy they used was generated from renewable sources or not. Previous studies (Dimeas et al., 2014; Morstyn and Mcculloch, 2018) similarly showed high environmental concerns among residential consumers. These consumers depicted other pro-environmental behaviors like adopting green electricity and energy conservation for air pollution control.

Here I also tried to find if there are regional variations in response to these three factors. An analysis of variance on environmental conservation (p-value=7.93E-11) (Table 6.1), air pollution associated with diesel power generation (p-value=1.75E-8), and power generation source (p-value=3.34E-7) (Table 6.2) showed significant statistical differences among the three study areas. Those who strongly cared about environmental conservation were mostly from Makueni County (72%), low-income category (56%), and middle and high-income category (54%). In Uasin Gishu County 84% cared about environmental conservation.

The respondents who were strongly worried about diesel power generated air pollution were from Makueni County (64%), Nairobi County city center (56%), middle-high-income category (52%), and low-income category (50%). About 94% of those in Uasin Gishu County were worried about it. Those who strongly cared about power generation sources were from Makueni County (54%), low-income category (48%), middle-high-income category (44%), and Nairobi County city center (44%). In Uasin Gishu County 68% of the respondents cared about it.

These results show that the respondents in Makueni County were more concerned about the three environmental issues than those in the other two counties. This could be partly because their livelihoods (agriculture and livestock keeping) are directly connected to the environment (KNBS, 2015b). Although the respondents in Uasin Gishu County were also dependent on farming, this County received higher rainfall with more forest cover (KNBS, 2015c).

I additionally conducted a multiple regression analysis to find the connection between the three identified environmental problems and the respondents' socio-demographic characteristics. The analysis result showed that education (p-value=2.42E-2) and income (p-value=1.8E-3) significantly affected their perceptions about air pollution from diesel power generation while income (p-value=2.81E-4) influenced their perception on environmental conservation. Interestingly, the household size also had a significant impact on perceptions of environmental conservation (p-value=3.22E-2) (Table 6.3) and power generation source (p-value=2.85E-2). I found that households with less than three persons and those with more than six persons showed their strong concerns about environmental conservation and energy sources whereas the households with three to five persons cared less about the environment and energy issues.

6.4.3 Power supply from renewable energy sources and government support

The third part of the questionnaire aimed to find out if residential energy consumers wanted to receive all their domestic electricity needs from renewable energy sources. I also sought to find out whether these consumers wanted to sell the energy they generated to the national or local grid. Additionally, I wanted to know the respondents' perception of government support as they try to invest in renewable energy sources. The result shows that about 84% of the respondents either strongly agreed or agreed to meet all their electricity demand by renewable sources. An analysis of variance (p-value=2.48E-4) indicated regional variations where all the respondents in Uasin Gishu and about 92% in Makueni demonstrated their positive responses (Table 6.4). In Nairobi

County, middle-high-income respondents (86%) showed a more positive response compared to those in the city center (76%) and low-income areas (66%).

In Makueni County, about 34% had all their electricity demand from a solar mini-grid while about 12% obtained entirely from solar PV with battery. In Uasin Gishu County, about 44% obtained electricity from both the national grid and solar PV while about 4% obtained entirely from solar PV with battery. This finding largely corresponds with an Australian study (Sommerfeld et al., 2017), in which homeownership was found to be an important factor for households to adopt renewable energy sources. A multiple regression analysis of the respondents' socio-demographic characteristics showed that age (p-value=4.09E-2) significantly influenced their perception of willingness to supply all their domestic electricity needs from renewable energy sources (Table 6.5). The majority of those who were willing to supply all their domestic electricity needs from renewable energy sources were those aged above 30 years.

Regarding the second question about respondents' interests in selling energy to grids, about 72% of them either strongly agreed or agreed to this idea while about 12% disagreed. An analysis of variance (p-value=2.53E-7) for their responses showed regional and income-level differences. All the respondents in Uasin Gishu County demonstrated their interests in selling power to grids. In Makueni County, about 72% showed their interests. In Nairobi County, about 74% of those in the middle-high-income level showed high interests while about 64% of those in the low-income level answered positively. A multiple regression analysis of the respondents' socio-demographic characteristics of age, gender, household size, education, and income levels did not show any significant effect on their interest to sell energy to the grids. These findings are supported by previous similar studies in Germany, France, Italy, and Australia (Hossain, Kamp, & Pachova, 2020; Yaqoot, Diwan, & Kandpal, 2016).

Regarding government support for residential consumers to invest in renewable energy, about 68% either strongly agreed or agreed while about 19% either disagreed or strongly disagreed. An analysis of variance (p-value=1.99E-4) indicated regional variations. In rural counties of Uasin Gishu and Makueni, 94% and 85% of the respondents acknowledged government support, respectively. In Nairobi County, 56% of the middle-high-income respondents, 65% of low-income, and 50% of the city center respondents acknowledged the same. Some facts could explain the reasons behind these differences. For example, in the past, the government support on renewable energy projects (especially off-grid) has been in rural areas. The multiple regression analysis of these responses in connection to respondent's socio-demographic characteristics indicates that education (p-value=1.62E-2) significantly affected their perceptions about government support.

6.4.4 Renewable energy technology choices

In the fourth section, I asked the respondents about what renewable energy technologies they would like to invest in. The question in this particular section targeted only those households (74%) that obtained all their electricity needs from the national grid. The result shows that about 85% would like to invest in solar PV, while only 2% and 1% showed interests in wind and small hydro respectively. About 6% would like to invest in the combination of sources like solar PV, wind, and small hydro. The rest had no interest in any form of renewable energy technologies.

Here I found different responses by region. In terms of investment in solar PV, the respondents in Makueni (94%) and Uasin Gishu (90%) wanted to invest in solar PV systems. In Nairobi County, the higher percentage of the middle-high-income group (86%) showed interests in solar compared to those in the low-income group (80%) and the city center (72%). Those respondents who showed interest in wind power were from Makueni County and the Nairobi County city center while all those who wanted to invest in small hydro were from Uasin Gishu County. The tendency of residents to show preference for solar energy can be found in other countries like Qatar (Abdmouleh et al., 2018) and Yemen (Baharoon et al., 2016).

I found that respondents' interests in investing in renewable energy were also influenced by financial and climatic factors. In Kenya, solar PV is relatively easy and affordable technology compared to small wind and hydro technologies. On the other hand, only limited areas in western, central, and eastern parts of the country have the potential for the small and large hydro generation (Kiplagat et al., 2011). This explains why all respondents who showed interest in small hydro developments were from Uasin Gishu County. Currently, most of the residential consumers who have invested in small hydro have done so through community projects which are relatively larger (Government of Kenya, 2018).

6.4.5 Motivation to invest in renewable energy sources

The fifth section of the questionnaire attempted to understand residents' motivations to invest in renewable energy technologies. The survey results revealed that the respondents were largely motivated to prevent electricity supply problems, such as frequent power outages (42%), high power cost (37%), and lack of connection to the national grid (11%) (Figure 6.1). Additionally, environmental concerns (6%) and low cost of renewable energy equipment (4%) motivated some respondents. Previous studies (Dimeas et al., 2014; Gadenne et al., 2011; Morstyn et al., 2018) similarly found that pro-environmental concerns did not always translate into actual actions.

Within a regional context, I found that frequent power outage was an important factor for the respondents in the Nairobi County city center (48%), while the high cost of power was more problematic for the low-income respondents (52%) in Nairobi County. For the respondents in Makueni County, a lack of connection to the national grid was the main motivator (30%). Interestingly, environmental concerns were not considered as a motivation factor by the respondents of Makueni County, Uasin Gishu County, and Nairobi County's low-income group even though 98% of the respondents indicated that they strongly cared or cared about environmental conservation.

The multiple regression analysis on correlations between respondents' socio-demographic characteristics and motivations indicates that income level (p-value=1.8E-3) significantly affected their motivation. Low-income respondents were motivated by frequent power outages and high energy costs. On the other hand, for the middle-high-income respondents' frequent power outages, high energy cost, and environmental concerns were equally worrisome.

6.4.6 Challenges facing the adoption of renewable energy technologies

The sixth section assessed the challenges the respondents would face in case they decided to install renewable energy technologies. About 46% said that the high cost of equipment was the main challenge (Figure 6.2). This was followed by the intermittent nature of renewable energy sources (31%), the lack of qualified personnel to install (16%), and lack of interest in renewable energy sources (7%). Previous studies on Kenya's renewable energy sector similarly found that high equipment cost was one of the major challenges for Kenyan consumers (Boampong & Phillips, 2016).

In terms of regional variations, 58% of those in the middle-high-income found this important, whereas 54% of those in the city center and 52% of low-income groups showed their concerns over the cost. On the contrary, the cost was less important in Makueni (38%) and Uasin Gishu (30%). In these two rural counties, I found that the intermittent nature of renewable energy was challenging whereas less than 30% of the respondents in all groups of Nairobi County indicated this as their challenge. The lack of skilled persons who can install solar PV was pronounced in Uasin Gishu County (36%) and Makueni County (18%). In Nairobi County, this is a challenge for a certain number of middle-high-income group (14%). All the respondents who had no interest in renewable energy sources were from Nairobi's city center (18%) and the low income (14%) groups. Although this number is small, it's very significant given that the majority of the respondents from the city center were young and over 50% of Kenya's GDP is generated in Nairobi. However, previous studies have shown that with increased adoption of renewables in a certain area, the probability of adoption and new installations even amongst those without interest rises significantly (Kowalska-Pyzalska, 2018).

The multiple regression analysis of these responses in connection to the respondent's socio-demographic characteristics indicates that education (p-value=2.38E-3) and household size (p-value=2.70E-2) significantly affected their perceptions on the challenges. In particular, the less educated respondents were more concerned with the intermittent nature of renewable energy sources and lack of skilled personnel for installation while the more educated ones were concerned with cost. Similarly, bigger households were concerned with the intermittence of renewables.

6.5 Summary

This chapter examined Kenya's residential consumers' willingness to supply their entire electricity demand with renewable energy sources. It also investigated factors that motivated and hindered the adoption of renewable energy technologies in three different regions of Kenya: Nairobi (urban county), Makueni, and Uasin Gishu (rural counties). The results showed that about 96% of the rural respondents and 76% of the urban respondents preferred to have all their electricity supplies from renewable energy sources. Additionally, about 86% rural and 63% urban respondents expressed their wish to sell the electricity they generate to the national grid. The main renewable energy technology that the respondents preferred to invest in was solar PV (85%).

However, I found that even though about 98% of the respondents showed their concerns about environmental conservation, this reason alone did not appear to motivate the respondents to invest in renewable energy. Instead, the respondents mainly wanted to secure a reliable electricity supply as they had often experienced power outages. The high and fluctuating energy cost from the grid system also motivated them to invest in renewable energy. In rural areas, the respondents were largely motivated by a lack of connection to the national grid. These rural residents acknowledged government support in adopting renewable energy technologies. What hindered the respondents most in adopting renewable energy technologies was the high cost of equipment and the intermittent nature of renewable energy resources. The latter reason was particularly more prevalent for rural residents.

Overall, this chapter showed that Kenyan urban and rural residential consumers were highly interested in renewable energy. Kenya's national policy to have its 100% electricity supply with renewables can be further expedited with a better understanding of regional differences in residential consumers' needs. As the past studies showed the importance of understanding regional differences in terms of consumers' perceptions about adopting renewable energy, this study can shed light on this topic in Kenya. This chapter also demonstrated that some of the findings corresponded with past studies about Europe and Australia. Within a policy improvement context, the findings of this chapter can better inform Kenya's development partners like the US, EU, China, and Japan. These countries provide funding for major energy projects in Kenya.

Table 6.1 ANOVA analysis of the concern for environmental conservation[17]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.304	4	3.326	14.772	7.93E-11	2.408
Within Groups	55.160	245	0.225			
Total	68.464	249				

[17] This table shows the analysis of variance on the respondents' concern for environmental conservation between the three counties (n=250)

Table 6.2 ANOVA analysis of the concern for the type of power sources used[18]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.216	4	4.304	9.565	3.34E-07	2.408
Within Groups	110.240	245	0.449			
Total	127.456	249				

Table 6.3 Multiple regression analysis of environmental conservation[19]

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.394	0.242	5.765	2.46E-08	0.918	1.870
Age	-0.035	0.043	-0.804	4.22E-01	-0.120	0.050
Gender	0.003	0.083	0.039	9.68 E-01	-0.161	0.168
Household size	0.219	0.102	2.155	3.22E-02	0.019	0.419
Education	-0.119	0.081	-1.477	1.41E-01	-0.279	0.040
Income	0.106	0.029	3.685	2.81E-04	0.049	0.162

[18] This table shows the analysis of variance between the three counties on the respondents' concern for the type of power sources they used (renewable or non-renewable sources)

[19] This table shows the results of multiple regression analysis of age, gender, household size, income and education against the respondents' concern for environmental conservation

Table 6.4 ANOVA analysis of the respondents' perception on electricity supply[20]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.304	4	3.076	5.604	2.479E-4	2.408
Within Groups	134.48	245	0.549			
Total	146.784	249				

Table 6.5 Multiple regression analysis on electricity supply with renewable energy sources[21]

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.090	0.280	7.453	1.59E-12	1.538	2.642
Age	0.109	0.053	2.055	0.041	-0.213	-0.005
Gender	0.009	0.099	0.088	0.929	-0.186	0.204
Household size	-0.057	0.056	-1.019	0.309	-0.168	0.053
Education	-0.004	0.046	-0.085	0.933	-0.095	0.087
Income	0.047	0.034	1.380	0.169	-0.020	0.115

[20] This table shows the analysis of variance between the three counties on the respondents' perception on receiving all their domestic electricity demand from renewable energy sources
[21] This table shows the results of multiple regression analysis of age, gender, household size, income and education against the respondents' willingness to receive all their domestic electricity demand from renewable energy sources

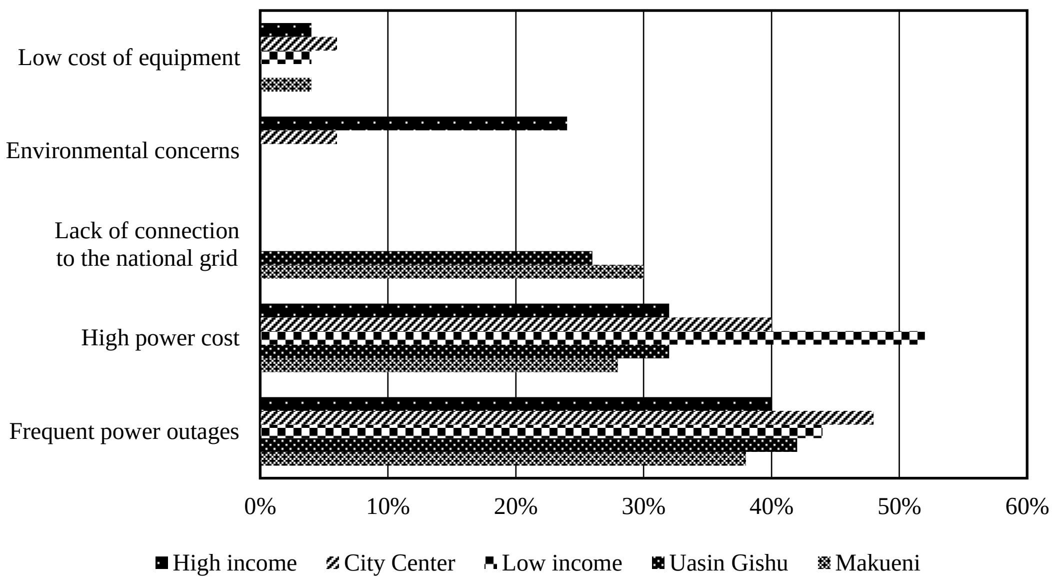

Figure 6.1 Motivation to invest in renewable energy sources[22]

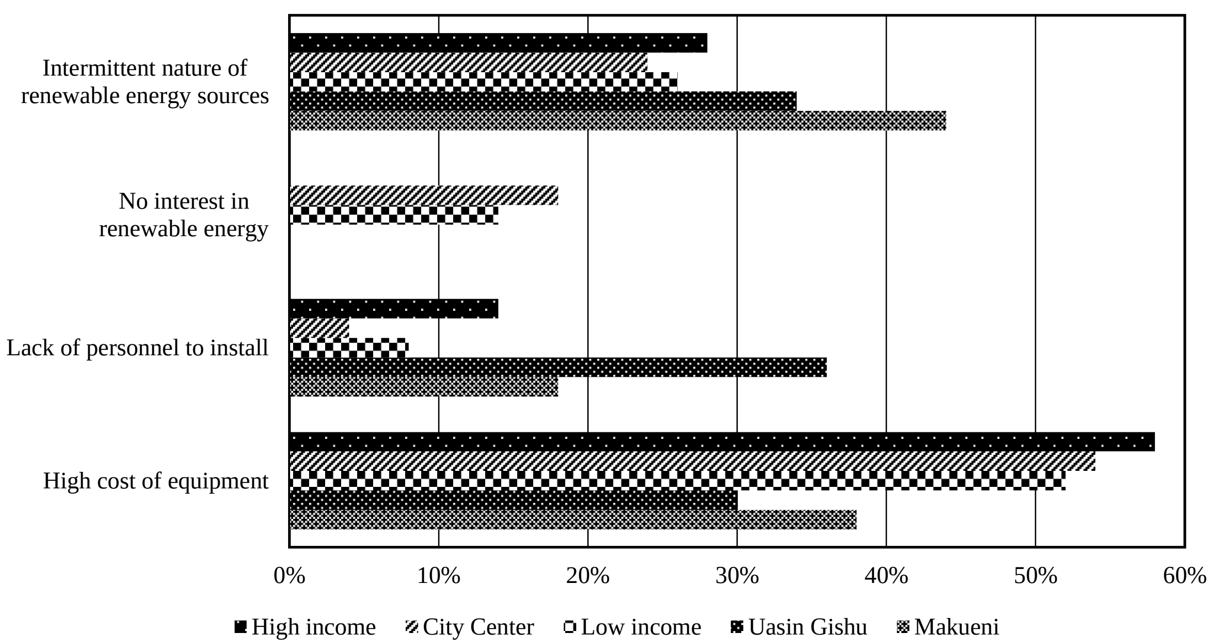

Figure 6.2 Challenges facing the adoption of renewable energy technologies[23]

[22] This figure shows residential consumer respondents' motivation to invest in renewable energy technologies. The X-axis represents the percentage of respondents.

[23] This figure shows the challenges faced by residential consumer respondents in adopting renewable energy technologies. The X-axis represents the percentage of respondents.

Chapter 7 Conclusion and recommendations

7.1 Main findings

This study provides an empirical basis to understand the evidence behind propositions for a 100% renewable energy. The outcomes are expected to provide a better understanding of renewable energy resource potential and consumer behaviors in Kenya. In the previous chapters, I investigated methods of addressing the challenges of 100% electricity supply with renewable energy sources in Kenya. First, I traced the historical development of Kenya's energy policies to gain insight into the changes over time and the impact it has had on the deployment of renewable energy sources (chapter 2). In chapter 3, I investigated Kenya's capacity to supply 100% of its electricity demand with renewable energy sources. Chapter 4 sought to address the variability and transmission challenges of 100% electricity supply with renewable energy sources in Kenya. In chapter 5, I investigated the future contribution of demand-side management in achieving a 100% electricity supply with renewable energy sources in Kenya. Finally, in chapter 6, I investigated regional contexts of residential consumers' decision-making for adopting renewable energy technologies in Kenya.

7.1.1 The historical development of energy policies and the future of renewable energy in Kenya (chapter 2)

I found that the initial policy formulation and evolution were heavily influenced by multilateral and bilateral financial institutions. However, over time, the local political dynamics have played a greater role in policy formulation especially in favor of generation from renewables with laws being passed immediately before or after a general election. As a result, Kenya has created a robust policy and regulatory framework that has seen a continuous increase in the share and the diversity of renewables in the national grid. The new energy act passed in 2019, provides an opportunity for further growth of renewables by promoting the adoption of renewables by residential and commercial consumers through net metering. I conclude that, given the strong policy and regulatory framework in place, heavy financial investments and resource availability, the commitment to renewable energy may not falter anytime soon.

7.1.2 An analysis of Kenya's capacity to supply 100% of its electricity demand with renewable energy sources (chapter 3)

In this chapter, the results of questionnaire survey I administered to Kenya's energy experts showed that geothermal, hydro and wind renewable energy sources were the most exploitable sources. About 76% and 41% of the respondents strongly agreed or agreed that Kenya could meet its electricity and entire energy demand respectively for 2030 with renewable energy resources while about 89% and 71% responded similarly for 2050. In achieving 100% supply from renewables, I found that the most effective policy options are: feed-in-tariffs (94%), zero-rating of import duties on renewable energy technology accessories (84%), investment subsidies (81%) and eliminating subsidies on fossil fuels (71%). Another noticeable finding that differs from many existing studies is the continued investment on renewables by investors and consumers even after the expiry of FiTs. These findings demonstrate that Kenya has adequate renewable energy resources to meet its electricity and entire energy demand for 2030 and beyond.

7.1.3 Addressing variability and transmission challenges of electricity supply with 100% renewable energy sources in Kenya (chapter 4)

I found that the most viable methods of dealing with variability under 100% renewable energy sources electricity supply are: using non-variable sources to help match demand with supply (81%), regional (74%) and national (61%) interconnection of geographically dispersed renewable energy sources, providing 100% of rural households electricity demand with renewables (71%), applying demand-response management and smart grid (68%), and using micro-grids (61%) run by renewable energy sources. In terms of transmission, currently, the respondents perceive that the deployment of wind power (53%) has been affected the most. To overcome transmission challenges in remote areas, the experts think that the use of mini-grids run by renewables (76%) is more economically viable compared to extending the national grid (41%). Another salient finding is that about 65% of the experts consider the electricity supply stability under 100% renewables as far better than now. Reflecting on these findings, I conclude that Kenya can overcome the challenges to supply its electricity demand with 100% renewables.

7.1.4 The future contribution of demand-side management in achieving 100% electricity supply with renewable energy sources in Kenya

I found a low level of familiarity with smart meters (24%), smart grid (20%), and demand-side management (43%) among the residential consumers' respondents especially those from the rural counties of Makueni and Uasin Gishu. However, to avoid power outage during peak hours, 88% of these respondents expressed their willingness to shift the period they use electricity permanently or sometimes. Their motivation for doing this is to save energy costs (65%) and environmental conservation (17%). Regionally, cost-saving motivated urban respondents more while rural respondents were motivated by environmental concerns. The energy expert respondents indicated that price-responsive demand (81%), household renewable energy adoption (74%), energy efficiency and conservation (64%), and integration of smart appliances (61%) were the most viable demand-side management options for Kenya. By implementing these options, about 48% of the respondents, mostly with postgraduate degrees, indicated that the peak demand would be reduced by over 50%. These findings show the crucial role that demand-side-management could play in achieving a 100% electricity supply with renewables.

7.1.5 Residential consumers' willingness to adopt renewable energy sources (chapter 6)

In this chapter, the results showed that about 96% of the rural respondents and 76% of the urban respondents preferred to have all their electricity supplies from renewable energy sources. Additionally, 86% of the rural and 63% of the urban respondents wanted to sell the electricity they generate to the grids. About 85% favored solar PV for this. I found that even though about 98% of the respondents showed their concerns about environmental conservation, this reason alone did not appear to motivate them to invest in renewable energy. Instead, the respondents mainly wanted to secure the steady electricity supply as they had often experienced power outages and the high and fluctuating energy cost from the grid. In rural areas, the respondents were largely motivated by a lack of connection to the national grid. What hindered the respondents most in adopting renewable energy technologies was the high cost of equipment and the intermittent nature of renewable energy resources. The latter reason was particularly more prevalent for rural residents.

7.1.6 Current challenges to meet 100% electricity demand with renewables in Kenya

In its quest to achieve a 100% electricity supply with renewables, Kenya has to overcome several challenges. First, there is a need to establish the country's economic renewable energy potential. This would be followed by investment in methods to mitigate the variability of renewable energy resources (wind and solar) and the intensive capital investment required for transmission. Currently, although the average electricity access rate nationally is 76%, there is still low access in rural areas. The other main challenge is the high peak demand that occurs between 18:30 and 22:00 necessitating the use of emergency power from diesel-powered generators. Although this could be mitigated through the application of demand-side management, this would not be possible until the national grid is modernized. By shedding light on the approaches that could be applied to overcome these challenges, my dissertation helps in contributing to SDG 7 on the provision of affordable, reliable, and clean energy by 2030. It also helps Kenya to achieve its goals under the United Nations Decade of Sustainable Energy for All (SE4All). Finally, it will contribute to the achievement of goals of National Determined Contribution (NDC) under the Paris Agreement.

7.2 Recommendations

I identified four areas that need to be improved so that Kenya can supply the entire electricity demand with renewables: (1) effective policy implementation, (2) renewable energy resources' exploitation (3) demand-side management (4) residential consumers' adoption of renewables. Below, I discuss my recommendations on how these areas can be improved in the future to achieve a 100% electricity supply with renewables.

(1) The government ought to focus on the full implementation of the Energy Act 2019 as it would promote the growth of renewables, especially through net metering. In this regard, further reforms are necessary to promote the participation of electricity consumers and the private sector in expediting renewable energy mini-grids in rural areas. Besides, the current renewables oriented political will could be maintained through institutionalization in the policymaking and implementation process.

(2) To promote renewable energy exploitation, I propose a fast-tracked process of renewable energy resource mapping, especially for geothermal, hydro, solar PV, and wind. The results from mapping need to be shared promptly with possible investors and consumers. With the expected economic difficulties in the wake of the Covid-19 pandemic, the government needs to work with banks and other financial institutions to promote credit financing of renewables for a sustainable and efficient market. The credit financing ought to be coupled with net metering to allow consumers to supply their power while repaying the debts. The

acquisition of renewable energy technology equipment could further be enhanced through tax incentives to lower the initial investment cost. In sparsely populated areas and far away from the grid, the government could introduce an off-grid policy that covers mini and micro-grids providing investor incentives and protection from political influence. The off-grid policy could be enhanced with a corresponding special FiT tariff for mini and micro grids below 500 kW to allow them to run independently.

(3) To promote demand-side management, I recommend the government to focus on educating consumers. The education ought to demonstrate its financial and environmental benefits. Additionally, it should apply tailor-made training and educational programs to individual consumers. In doing this, as my research showed, conventional media, training in schools, and the use of social media, among young residential consumers, could be more convenient mediums. There is also a need to provide low-income consumers with a means of obtaining demand-side management equipment like smart meters and in-home displays. The government should provide incentives so that they can shift consumption to periods of high supply from renewables. Apart from price-responsive demand, grid modernization would facilitate real-time two-way communication between the utility and consumers.

(4) To promote renewable energy technologies, I recommend that the government focus on providing incentives for purchasing generation equipment. In rural areas, financing and training of the locals to facilitate investment in solar PV and small hydro would facilitate the processing of agriculture produce in line with the government's food security agenda. There is also a need to promote local participation beyond the current environmental impact assessment. Additionally, there is a need to share local and international experiences to promote the acceptance of renewable energy projects. Although pay-as-you-go systems of payment have promoted the adoption of solar PVs, there is a need for the government to ensure consumers get the value for their money. Given that the majority of low-income consumers have lost income during the coronavirus pandemic, the government could support them by connecting its recovery plan to income generation through renewables.

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Appendices

Appendix I: Assessing Kenya's Capacity to Supply 100% of its Electricity with Renewable Sources

The objective of this questionnaire is to better understand Kenya's electricity sector with regard to electricity demand, energy supply sources, and energy policy. In particular, I would like to know the extent to which electricity demand can be supplied with renewable energy sources by 2030. Your responses will be analyzed to write a doctoral dissertation and academic papers. All information I obtain from you will be treated confidentially and will not be shared with any other interest groups or individuals. I will safely store the information for the legally prescribed duration of time.

Instruction: Tick (√) response codes and indicate details where necessary.

Location…………………………… **Date…………………..**

NB: The renewable energy sources under consideration in this survey are: Hydro, geothermal, wind, solar, and biomass.

SECTION A: DEMOGRAPHIC CHARACTERISTICS

Q1. Age	20-29 years ☐ 30-39 years ☐ 40-49 years ☐ 50-59 years ☐ Over 60 years ☐			
Q2. Gender	Male ☐ Female ☐			
Q3. Name of Organization/Agency				
Q4. Department/Position				
Q5. Years of Experience	Below 5 years ☐ 5-10 years ☐ Above10 years ☐			
Q6. Highest level of education completed?	High school ☐	Diploma ☐	Bachelor's ☐	Masters/PhD ☐

SECTION B: RENEWABLE ENERGY POTENTIAL AND ENERGY DEMAND

Q7. In your own opinion, to what extent will the electricity demand in Kenya increase by 2030 compared to 2018?

No change ☐ 2 times ☐ 3 times ☐ 4 times ☐ 5 times or more ☐ Decrease ☐

Q8. Of the available technical potential, what is the % of economic potential for:						
		Less than 50%	50-59%	60-69%	70-79%	More than 80%
a	Biomass					
b	Geothermal					
c	Hydro					
d	Wind					

Q9. To what extent do you agree that Kenya has enough renewable energy potential to meet electricity and overall energy demand in the following scenarios?						
		Strongly agree	Agree	Not sure	Disagree	Strongly Disagree
a	2030 projected electricity demand					
b	2050 electricity demand					
c	Entire energy demand for all purposes in 2030					
d	Entire energy demand for all purposes in 2050					

Q10. To what extent do you agree with the following statements?						
		Strongly agree	Agree	Not sure	Disagree	Strongly Disagree
a	Kenya’s energy policy emphasizes fossil fuels					
b	Kenya’s energy policy emphasizes renewable sources					
c	Kenya’s energy policy can achieve a 100% renewable energy supply					

Q11. How would you rate Kenya's technical capacity to achieve a 100% renewable energy goal by 2030?

Very High ☐ High ☐ Average ☐ Low ☐ Very low ☐

Q12. Under 100% electricity supply with renewables, to what extent do you agree that, the economic savings from fuel cost avoidance (thermal power plant) will help meet the transmission costs?

Strongly agree ☐ Agree ☐ Not sure ☐ Disagree ☐ Strongly disagree ☐

SECTION B: ENERGY POLICY

Q13. To what extent do you agree that the following energy policy options effectively promote the adoption of a 100% renewable electricity supply?

	Policy	Strongly agree	Agree	Not sure	Disagree	Strongly Disagree
a	Feed-in tariffs (FiTs)					
b	Auctioning					
c	Investment subsidies					
d	Zero-rating of import duties on renewables equipment					
e	Eliminating subsidies for fossil-fuel energy systems					
f	Taxing fossil-fuel use to reflect its environmental damages					

Q14. Investment in renewable energy sources has increased significantly as a result of feed-in-tariffs (FiTs). In your opinion, will investors and electricity consumers continue investing in renewable energy after FiTs expire?

Very likely ☐ Likely ☐ Maybe ☐ Unlikely ☐ Very unlikely ☐

Appendix II: Addressing the Variability and Transmission Challenges of a 100% Electricity Supply with Renewable Energy Sources in Kenya

The objective of this questionnaire is to understand the impact of high uptake of renewable energy sources on the national power grid. Specifically, I would like to know the strategies of overcoming variability and transmission challenges to achieve stable power grid under 100% electricity supply with renewable energy sources. Your responses will be analyzed to write a doctoral dissertation and academic papers. All information I obtain from you will be treated confidentially and will not be shared with any other interest groups or individuals. I will safely store the information for the legally prescribed duration of time.

Instruction: Tick (√) response codes and indicate details where necessary.

Location…………………………… Date…………………..

Definition of abbreviations used: EAPP – Eastern Africa Power Pool

SECTION A: DEMOGRAPHIC CHARACTERISTICS

Q1. Age	20-29 years ☐ 30-39 years ☐ 40-49 years ☐ 50-59 years ☐ Over 60 years ☐			
Q2. Gender	Male ☐ Female ☐			
Q3. Name of Organization/Agency				
Q4. Department/Position				
Q5. Years of Experience	Below 5 years ☐ 5-10 years ☐ Above10 years ☐			
Q6. Highest level of education completed?	High school ☐	Diploma ☐	Bachelor's ☐	Masters/PhD ☐

SECTION B: RELIABILITY UNDER 100% RENEWABLE ENERGY SOURCES ELECTRICITY SUPPLY

Q7. Compared to the current state, how would you rate the reliability of electricity supply under 100% renewable sources?

Far better than now ☐ Better than now ☐ Same as now ☐ Slightly worse than now ☐
Far much worse than now ☐ I can't tell ☐

Q8. In your assessment, how do you rate the feasibility of the following methods in dealing with the variability of renewable energy sources?						
		Very high	High	Average	Low	Very low
a	Nationally interconnecting geographically dispersed renewable energy sources					
b	Regionally (EAPP) interconnecting geographically dispersed renewables					
c	Using non-variable sources to help match demand with supply					
d	Applying smart grid and demand-response management to shift flexible loads to better match the availability of renewable energy sources					
e	Pumped hydro and battery storage					
f	Providing 100% of rural households power with renewables energy e.g solar PV with battery storage					
g	Use of micro-grids run by renewable sources of energy					

SECTION C: TRANSMISSION

Q9. Currently, to what extent does transmission negatively affect the deployment of the following renewable energy sources of energy?						
		Very high	High	Average	Low	Very low
a	Biomass					
b	Geothermal					
c	Hydro					
d	Wind					

Q10. Under 100% electricity supply from renewables, to what extent do you agree that, the economic savings from fuel cost avoidance (thermal power plant) will help meet the transmission costs?

Strongly agree☐ Agree ☐ Not sure ☐ Disagree☐ Strongly disagree ☐

Q11. In your own opinion, how do you rate the economic viability of the following power supply transmission options?						
		Very high	High	Average	Low	Very low
a	Extending the national grid to all parts of the country					
b	Mini-grids run with renewable energy sources in remote areas					

SECTION D: DEMAND SIDE MANAGEMENT

Q12. With the full implementation of demand-side management programs, to what extent would the current peak demand be reduced?

Less than 20%☐ Between 20-29%☐ Between 30-39%☐ Between 40-50%☐ Over 50%☐

Q13. How do you rate the viability of the following methods of demand-side management?						
	Policy Intervention	Very high	High	Average	Low	Very low
a	Price-responsive electricity demand					
b	Energy efficiency and conservation					
c	Renewable energy integration					
d	Smart metering and distribution automation					
e	Integration of smart appliances (e.g in-home display units)					

Appendix III: Consumers' Perception and Willingness to Adopt Renewable Energy Sources and Demand Side Management Practices

The objective of this questionnaire is to better understand your energy demand so that Kenyan consumers can have better energy management in the future. In particular, I would like to know the extent to which you are interested in renewable energy sources as well as cutting energy costs. In addition, I would like to know your level of awareness and willingness to adopt demand side management practices in managing energy consumption. Your responses will be analyzed to write a doctoral dissertation and academic papers. All information I obtain from you will be treated confidentially and will not be shared with any other interest groups or individuals. I will safely store the information for the legally prescribed duration of time.

Instruction: Tick (√) response codes and indicate details where necessary.

County…………………… Constituency…..………………………… Date……………..

SECTION A: DEMOGRAPHIC CHARACTERISTICS

Q1. Age	Under 20☐ 20-29 years☐ 30-39 years ☐ 40-49 years☐ 50-59 years☐ Over 60 years☐
Q2. Gender	Male☐ Female ☐
Q3. Occupation	
Q4. Number of members in the household	1-2 ☐ 3-4☐ 5-6 ☐ 7-8☐ 9-10☐ Over 10☐
Q5. Highest level of education completed?	No formal education ☐ Primary School ☐ High school☐ Diploma☐ Bachelor's☐ Masters/PhD ☐
Q6. Average monthly income (KES)	Less than 10,000☐ 10,000-20,000☐ 20,001-50,000☐ 50,001-80,000☐ 80,001-100,000☐ 100,001-150,000☐ 150,001-200,000☐ Over 200,000☐

Definition of initials used: KES=Kenya Shillings; KPLC=Kenya Power and Lighting Company, ERC=Energy Regulatory Commission, PV=Photovoltaic, KAM=Kenya Association of Manufacturers

SECTION B: DEMAND SIDE MANAGEMENT

Q7. To what extent are you familiar with the following terms/technologies and their advantages?						
		Very familiar	Familiar	Not sure	Not familiar	Very unfamiliar
a	Smart meters					
b	Smart grid					
c	Demand-side management					

Q8. How did you get to know about smart meters, smart grid, and demand-side management?

KPLC/ERC training☐ Radio/TV programs☐ Newspaper☐ Social media☐ School/college ☐

Q9. Are you aware of the demand side management promotion programs by KPLC/ERC/KAM?

Yes ☐ No ☐ Not sure ☐

Q10. If you can have access to your real-time electricity cost through advanced metering infrastructure, are you willing to shift your power consumption to a time when prices are lowest?

Always ☐ Sometimes☐ Not at all ☐

Q11. To what extent are you willing to do the following?					
		Willing	Somehow willing	Unwilling	Not sure
a	Invest in real-time home display monitors (for checking real-time power consumption)?				
b	Pay for a smart meter?				

Q12. What would motivate you to adopt demand-side management practices e.g in-home display monitors or smart meters (for real-time power consumption display)?

Energy cost savings ☐ Environmental concerns☐ Information gathering ☐

Technological curiosity☐ Others (please specify) …………………………………………..

Q13. To what extent do you agree that you will adopt the following programs if it was started by KPLC?						
		Strongly agree	Agree	Somehow agree	Disagree	Strongly Disagree
a	A mobile application for smartphones displaying electricity consumption information (e.g. cost of electricity, appliance electricity usage)					
b	A mobile application for smartphones connected to your bank/MPESA for paying electricity bills					
c	Function on the in-home display, which would allow you to predict the cost of the next electricity bill, by inputting different usage information for your appliances					

SECTION C: RENEWABLE ENERGY

Q14. To what extent do you care about the following?					
		Strongly care	Care	Not sure	Do not care
a	Environmental conservation				
b	Air pollution from power generation				
c	Power generation source for the power you use (whether it's from renewable or non-renewable sources)				

Q15. Currently, what is your electric power source?

100% National grid (KPLC) ☐ National grid (KPLC) & Solar PV ☐ Local diesel power plant☐ Local grid with renewable sources☐ 100% Household solar PV + Battery☐ 100% Household solar PV (no battery) ☐ Not connected to any electric power source☐

Q16. What kind of renewable energy sources would you like to invest for power supply to your household? (You can tick more than 1 box)

Solar PV ☐ Wind ☐ Small hydro ☐ Biomass ☐ None☐

Q17. To what extent do you think Solar PV with battery could supply your household electrical energy needs?

0-9%☐ 10-19% ☐ 20-29%☐ 30-39% ☐ 40-49% ☐ 50-59% ☐ 60-69% ☐ 70-79% ☐ Over 80%☐

Q18. Have you installed a solar PV system for your premises?

Solar PV only: Yes☐ No ☐

Solar PV + Battery: Yes☐ No ☐

Q19. If not yet installed, have you considered installing a PV system?

Solar PV only: Yes☐ No ☐

Solar PV + Battery: Yes☐ No ☐

Q20. What motivated/would motivate you to install a solar PV system?

Frequent power outages ☐ High power cost☐ Lack of connection to the grid ☐ Environmental concerns ☐ Low cost of equipment☐

Q21. To what extent do you agree with the following statements?						
		Strongly agree	Agree	Somehow agree	Disagree	Strongly Disagree
a	I want to supply all my domestic power needs with renewable energy.					

b	I want to sell the energy I generate with my solar PV to the national/local grid.					
c	The government gives me enough incentive to invest in renewable energy technologies?					

Q22. What are the main challenges of investing in renewable energy like solar PV with a battery?
High cost of equipment☐ Inadequate knowledge on its advantages☐ Lack of personnel to install☐ No interest in renewable energy☐ Inaccessibility of equipment☐
Intermittent nature of renewable energy sources☐

Appendix IV: Permission to conduct research

MINISTRY OF ENERGY

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When replying please quote
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Ref. No. ME/2/7/1

10th June 2018

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Dear Eliud,

RE: PERMISSION TO CONDUCT RESEARCH

We acknowledge receipt of your letter dated 13th May 2018 and requesting for the above captioned subject.

We have further noted that you intend to undertake research titled "**Addressing the challenges of 100 % electricity supply with Renewable Energy sources in Kenya's national grid**", this being your PhD dissertation.

The purpose of this letter therefore is to confirm that the Ministry of Energy does not have any objection to this study. You are therefore permitted to proceed. The Ministry will be happy to support where necessary and look forward to the findings of the research.

Yours Sincerely

PAUL N. MBUTHI
For: PRINCIPAL SECRETARY