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Cohen ANG'U

Assessing the Impact of Fast Variables on Resilience of Electrical Energy in View of Climate Change and Energy Security in Kenya

Defended on 06/09/2018 Before the Following Committee:

Chair	Megnounif Abdellatif	Prof.	University of Tlemcen
External Examiner	Alexander Pogrebnoi	Prof.	The Nelson Mandela African Institute of Science and Technology
Internal Examiner	Abdelhalim Benmansour	Prof.	University of Tlemcen

DECLARATION

I COHEN ANG'U, hereby declare that this research project represents my own work, realized to the best of my knowledge, without plagiarism. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

Sign: Date: 09/09/2018

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CERTIFICATION

This final version was submitted with the approval of the supervisors, and all corrections were added as recommended by the examination committee

COHEN ANG'U

Sign: Date: 09/09/2018

Reg.No.: PAUWES/2016/MEP01

PROF. JOHN N. MUTHAMA

Sign: **Date: September 11, 2018**

UNIVERSITY OF NAIROBI,
Wangari Maathai Institute for Peace and Environmental Studies

DR. OLUDHE CHRISTOPHER

Sign: Date: 12/09/2018

UNIVERSITY OF NAIROBI,
Department of Meteorology and Institute for Climate Change and Adaptation (ICCA)

ABSTRACT

This project assessed the impact of fast variables on resilience of electrical energy in Kenya. To achieve this objective, the study established trends in electrical energy selected system components, determined relationships among resilience metrics, electricity price, fuel shocks and electrical energy and developed scenarios for projecting future electricity prices for Kenya. The study focused on advancing empirical evidence in resilience assessment hence utilized both quantitative and qualitative approaches. Monthly and annual data on electricity generation, electricity prices, electricity sales, electricity imports and transmission and distribution losses was sourced from the Kenya National Bureau of statistics. Global oil prices data used was from West Texas Intermediate. Time series analysis, correlation and regression analysis methods were employed in this study. Further analysis for diversity, spare capacity and system effectiveness were performed. Electricity generation portrayed seasonality with generally increasing trend for most sources. Oil price shocks were found to affect both electricity price and generation while diversity and imports metric significantly correlated with electricity price. Thermal generation is used as a surrogate for hydropower and holds most of spare capacity. A regression model predicted price outcomes against observed prices and could be used to establish future trends in electricity prices. Policy intervention measures ought to be taken by policy and decision makers to avoid overreliance on hydropower and thermal generation in a bid to stabilize electricity prices. This study will form a benchmark for understanding and deployment of measures for energy security in Kenya's energy policy, vision 2030 and green growth strategy.

RÉSUMÉ

Ce projet a évalué l'impact de variables rapides sur la résilience de l'énergie électrique au Kenya. Pour atteindre cet objectif, l'étude a établi des tendances dans les composants du système de sélection de l'énergie électrique, déterminé les relations entre les paramètres de résilience, les prix de l'électricité, les chocs énergétiques et L'étude axée sur l'évolution des preuves empiriques dans l'évaluation de la résilience a donc utilisé des approches à la fois quantitatives et qualitatives. Les données mensuelles et annuelles sur la production d'électricité, les prix de l'électricité, les ventes d'électricité, les importations d'électricité et les pertes de transport et de distribution ont été fournies par le Bureau national des statistiques du Kenya. Les données sur les prix mondiaux du pétrole utilisées provenaient de West Texas Intermediate. Des analyses de séries chronologiques, des méthodes d'analyse de corrélation et de régression ont été utilisées dans cette étude. Une analyse plus poussée de la diversité, de la capacité de réserve et de l'efficacité du système a été effectuée. La production d'électricité montre la saisonnalité avec une tendance généralement à la hausse pour la plupart des sources. Il a été constaté que les chocs sur les prix du pétrole affectaient à la fois le prix de l'électricité et la production, tandis que la métrique de la diversité et des importations présentait une corrélation significative avec le prix de l'électricité. La production thermique est utilisée comme substitut de l'hydroélectricité et détient la plus grande partie des capacités inutilisées. Un modèle de régression prédit les résultats des prix par rapport aux prix observés et pourrait être utilisé pour établir les tendances futures des prix de l'électricité. Les décideurs et les responsables politiques devraient prendre des mesures d'intervention afin d'éviter une dépendance excessive vis-à-vis de la production d'hydroélectricité et de centrales thermiques afin de stabiliser les prix de l'électricité. Cette étude constituera une référence pour la compréhension et le déploiement de mesures de sécurité énergétique dans la politique énergétique du Kenya, la vision 2030 et la stratégie de croissance verte.

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ACRONYMS AND ABBREVIATIONS

EPP	– Emergency Power Producer
ERC	– Energy Regulatory Commission
FCC	– Fuel Cost Charge
GDP	– Gross Domestic Product
GEA	– Global Energy Assessment
GHGs	– Green House Gases
IA	– Inflation Adjustment
IEA	– International Energy Agency
IPCC	– Inter-governmental Panel on Climate Change
IPP	– Independent Power Producer
KenGen	– Kenya Generation
KES	– Kenya Shilling
KNBS	– Kenya National Bureau of Statistics
KPLC	– Kenya Power and Lighting Company
kWh	– Kilowatt-hour
MOE	– Ministry of Energy
MW	– Megawatt
RE	– Renewable Energy
REP	– Rural Electrification Program
VAT	– Value Added Tax
WARMA	– Water Resource Management Authority
WTI	– West Texas Intermediate
LTWP	– Lake Turkana Wind Power

Definition of Key Operational Terms

Oil shocks: Fluctuations in oil prices which may emanate from changes in either supply of or the demand for oil.

Diversity: A measure of possible energy alternatives. Is generally proposed as the first (and often only) principle for enhancing energy resilience but is also a defining characteristic of energy security

Spare Capacity/Reserve Capacity: Is the difference between the amount of electricity generated in a year, and the amount of electricity that could be generated at full capacity, normalized by applying total spare electricity available for use in the economic activity.

System Structure: Is defined by efficiency and order of the system and it includes 3 separate metrics; the efficiency of generation, imports of fuel for generation, and imports of electricity.

Resilience: is the ability of the energy system to provide and maintain an acceptable level of service in the face of various faults and challenges to normal operation.

Resilience metrics: Indicators that are used to measure resilience eg. Diversity, spare capacity and structure.

Fast Variables: These are variables that have shorter turn over times

CHAPTER ONE

INTRODUCTION

Energy, particularly electricity and solar energy, is the driving force of the majority of economic activities in developing countries. A bigger part of global energy is consumed in cities. Urban areas are characterized by large population densities with the population expected to increase in the coming decades. This is expected to have significant implications for future energy supply and demand. Non-renewable energy dominates energy use in many countries which has led to a rapid growth in Carbon dioxide emissions. Most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC, 2011). The projected significant increase in energy consumption would further enhance emission of greenhouse gases into the atmosphere, thereby intensifying climate change. Adaptation measures are required because climate change is already occurring which will have severe impacts on the urban energy system (IPCC, 2011).

Energy security is the ability of an energy system to supply energy to meet demand at an affordable price (Molyneaux *et al*., 2016). For better functioning of an economy, uninterrupted supply of energy is critical. The energy sector plays a critical role in a country's development as outlined by the Sustainable Development Goals (SDGs). In fact, achieving some of the SDGs would not be possible without adequate energy supply and infrastructure. SDG goal number seven not only spells out the need for clean energy but also emphasizes access to affordable energy. Electricity is widely known to be the best form of energy for modern energy needs. Therefore, talks about energy supply are usually centred about electricity supply. Developed countries have robust electricity networks that have been developed over time thanks to the abundance and discovery of fossil fuels. However, most countries have in the recent times started to exploit their vast renewable energy potentials particularly in the wake of debate about climate change.

While fossil fuels cannot be completely eliminated from the energy mix, over reliance on these energy resources poses a big threat to a country's energy supply in case of uncertainties in the oil markets and oil supply. Fossil fuels particularly oil have a share in the energy mix of most countries because they dominate the transport sector.

1.1 Background of Study

Essential dynamics of a given system can be captured by including the key processes with longer and shorter turnover times (slower or faster turnover rates). When initiating a study of an energy system process, it is known that the context is set by other processes with longer turnover times. The mechanisms of these systems derive from another set of processes with shorter turnover times. Fast and slow variables of a system are terms that are common in ecosystems dynamics. In ecology, fast variables of the system show the dynamics of the underlying structural variables (Carpenter, Walker, Anderies, & Abel, 2001). If this assertion is applied to electricity generation, price may represent the fast variable since it reflects the dynamics of the structure transforming fuel source to electrical energy. Thus, if price can show levels of stability, despite volatility in structural components, then there is evidence of resilience in electricity generation (Molyneaux *et al*., 2016).

The concept of resilience is closely linked to sustainability as an umbrella concept that is aimed at maintaining socially, economically and environmentally desired human-environment interactions over time. The Global Energy Assessment (GEA, 2012) describes resilience as the third 'perspective' of energy security after the perspectives of robustness (protection from predictable events) and sovereignty (protection from non-domestic supply disruption) while resilience is considered as the ability to adapt to unpredictable weather events and political instability. According to the International Energy Agency (IEA, 2011), resilience of the energy sector refers to the capacity of the energy system or its components to cope with a hazardous event or trend, responding in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation.

An energy resilient electricity supply system should be able to ensure availability, accessibility, affordability, and acceptability of energy supply, under varying conditions, through enhancing its ability to plan/prepare for disaster, absorb its initial shocks, recover rapidly, adapt and self-organize (Sharifi & Yamagata, 2015). Several approaches to assessing resilience have been proposed by different scholars. There exist both qualitative and quantitative approaches to assessing energy resilience.

Resilience of an energy system can be assessed using a conceptualized framework which characterizes an energy resilient system. This is achieved using a matrix that includes various planning and design criteria that are related to energy supply, transmission, and distribution (Sharifi & Yamagata, 2015). According to Roege *et al*., 2014, in a disaster resilience framework, four critical components to resilience have been identified as plan/prepare, absorb, recover and adapt. The qualitative studies use metrics that are assessed through measures to represent low, medium or high levels of resilience. There are also numerical approaches to assessing resilience achieved through the use of empirical evidence to seek for present characteristics in electricity generation. This involves the use of certain models to establish the statistical significance of different metrics in predicting the dependent variable. Globally, such an approach has been used in the United States to determine resilience in electricity generation. This is presented in a study by Molyneaux *et al.*, 2016. This study will adopt a quantitative approach to establish empirical evidence in resilience of electrical energy.

1.2 Problem Statement

The need to create more resilient energy systems has to intersect with the need to establish cleaner and more efficient energy systems. Electricity generators will have to respond to the changes required for a carbon free future. This is one of the most serious challenges for planners and policy makers in the field of energy. Whilst many discussions on measuring energy resilience point to metrics, only a few suggest the use of dependent variable, which might be used to gauge the performance of the metrics proposed. For instance, He *et al.*, 2015 presented an energy import resilience index using input-output linear programming models, while (Chuang & Ma, 2013) analysed the impact of energy diversity in reducing risk of energy supply shortages and cost fluctuations. Sharifi and Yamagata (2015) developed a conceptual framework for assessment of urban energy resilience for sustainability of an energy system. The framework is based on the four facets of availability, accessibility, affordability and acceptability.

These studies have attempted to explain resilience in energy systems using qualitative approaches. Despite the importance of energy resilience for the survival of any country's energy sector, review of the available literature shows that it is still an understudied concept and warrants further investigation. It is the limited information on empirical evidence in measuring resilience for energy systems and the absence of similar studies in Kenya that is the motivation for this study. Resilience in this study will be applied in the context of energy security.

1.3 Hypothesis

a) Electrical energy exhibits seasonality.
b) If there is variation in climate, there is a corresponding fluctuation in electrical energy
c) If global oil prices, spare capacity and diversity increase then electricity prices increase, decrease and stabilize respectively.
d) If policy formulation improves then electricity prices will stabilize

1.4 Objectives

1.4.1 General Objective

The overall objective of this study was to assess the impact of fast variables on resilience of electrical energy in view of climate change and energy security in Kenya.
To achieve this objective, the following specific objectives were carried out:

1.4.2 Specific Objectives

a) To investigate inter-annual and intra-annual temporal patterns of electrical energy selected system components
b) To determine the effects of climate change signals on selected electrical energy system components
c) To establish the relationships among oil shocks, electricity price, resilience metrics and electrical energy
d) To develop scenarios for projecting future electricity prices for Kenya

1.5 Significance of the study

The Paris Agreement of 2015 saw much emphasis on the need to transform our energy systems mainly from the business as usual scenario (fossil fuels) to decarbonized energy systems. For instance, in 2013 about 23.3 trillion kilowatt hours were generated for billions of consumers around the globe, resulting in 13.4 billion tons of carbon dioxide emissions added to the stock of greenhouse gases which will impact the global climate (IEA, 2015). Unless drastic measures are taken, the projected significant increase in the global energy consumption would in turn result in further emission of greenhouse gases (GHGs) into the atmosphere, thereby intensifying climate change. Climate change will result in increased occurrence of hot spells and severe and longer winters.

Consequently, the demand for cooling and heating energy will increase and given the expected depletion of oil reserves and fuel price rises, meeting this increased demand will be a huge challenge. The costs of energy supply interruptions will be too high for economic growth of countries. The challenge ahead is twofold in that on one hand, as the global average temperature increases with the increase in the cumulative CO_2 emissions, severe mitigation measures are needed to limit warming to two degrees as spelt out in the Paris Agreement. On the other hand, adaptation measures are required because climate change is already occurring and will have severe impacts on the energy systems irrespective of the future trajectories of GHG emissions.

Kenya's Ministry of Energy 2013-2017 Strategic Plan Outlines Energy as one of the key enablers of the vision 2030 and describes energy security as a matter of national priority. Kenya's greatest energy challenge is the meagre 2,298 MW of installed electricity generation capacity as of 2015 which represents approximately 45 MW per million people (Kenya Vision 2030, 2016). Expensive energy hinders Kenya's competitiveness by raising the cost of doing business. In this regard, energy accessibility and cost are key priorities of the Ministry of Energy and Petroleum. (Ministry of Energy and Petroleum Strategic Plan 2013-2017, 2014). The energy sector in Kenya relies wholly on the importation of all petroleum requirements. However, with the recent discovery of oil in Northern Kenya this trend is likely to change.

The main objective of Kenya's energy Policy is to ensure affordable, competitive, sustainable and reliable supply of energy to meet national and county development needs at least cost, while protecting and conserving the environment (Ministry of Energy and Petroleum, 2014). In this energy policy document, both energy security presented in terms of sustainability and reliability and energy accessibility at least cost are identified as major areas of concern in the Kenya's energy sector. While addressing energy needs in Kenya, attention is also given to the environment and this will call for deployment of clean energy technologies. In order to achieve fast growth and development, Kenya will have to integrate its abundant renewable energy resources with fossil fuels while gradually doing away with fossil fuels. Despite the ongoing developments in its renewable energy sector, Kenya has not shown intentions to stop exploiting its fossil fuel base with coal well set to enter the energy mix for electricity generation. A challenge is posed in terms of development and the need for clean energy.

How can an economy which relies heavily on wood fuel and biomass as its largest energy source, achieve sustainable energy use through the gradual increase in the use of renewable energy sources that are often expensive due to the technology deployed, in the face of oil and coal discoveries that could be more readily accessible in spite of its known effects on the environment (Institute of Economic Affairs, 2015). This challenge will require careful implementation of energy sector reforms to ensure that not only the newly discovered non-renewable energy resources are developed but also to put in place a framework that ensures diversification of energy sources with focus on making renewable energy sources competitive. This calls for research into the possible scenarios subject to the policy guidelines outlined by the National Energy Policy.

This study is an attempt to understand how fluctuations in oil prices affect electrical energy in Kenya. There is increasing study about the importance of resilience across disciplines as a concept to understand the capacity of systems or individual to respond to change. Resilience thinking is chosen as a core concept for a more holistic view on sustainable energy system development and energy security. The findings of this study will benefit a broad cross-section of users including government planners and also enable them to make informed decisions. The findings will also help the government to pursue improved disaster planning policies that promote investment in resiliency.

1.6 Scope of the study

1.6.1 Geographical Scope

This study focused on the Republic of Kenya as a case study. Kenya is located in East Africa and borders Uganda to the west, Ethiopia and South Sudan to the north, Tanzania to the south, Somalia to the East and the Indian Ocean to the South East. The choice to conduct the study for the whole of Kenya is informed by the fact that electricity generation, supply and distribution is centralized.

1.6.2 Content scope

The focus of this study was to assess the impact of fast variables on resilience of electrical energy. The fast variables comprised electricity price and fuel shocks with the former being the dependent variable. Resilience metrics formed the independent variables.

1.6.3 Time Scope

This study serves as a requisite for the award of a Masters degree and was therefore conducted in accordance with the university’s academic schedule. The study commenced in March, 2018 for a period of 6 months up to August, 2018. There were no time preferences for the best timing to conduct this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Different studies have been carried out in an attempt to describe and measure resilience in energy systems. Although the literature available on resilience covers a wide range of topics in energy and system theories, this review will focus on three major themes that are persistent throughout the reviewed literature. The three areas are: resilience theory and metrics, system variables (oil shocks, electricity price) and empirical evidence. This section will primarily focus on the findings and applications of the literature reviewed.

2.2 Theoretical Review

This study is about the impact of fast variables in determining resilience in electrical energy. The fast variables are identified as electricity prices and fuel shocks. Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variable and parameters and still persist. Resilience has in recent times entered energy policy papers. The Energy Union Package of the European Commission is titled “A Framework Strategy for a Resilient Energy Union”. Resilience is mentioned as a desirable goal and is understood as decreasing the risk of potential energy disruptions. Greater resilience to climate change impacts will be essential to the technical viability of the energy sector and its ability to cost-effectively meet the rising energy demands driven by global economic and population growth (IEA, 2015).

2.2.1 Resilience theory and resilience Metrics

Resilience theory is a broad multidisciplinary concept that addresses the strengths that people and systems demonstrate which enable them to rise above adversity. In some disciplines, the theory is well developed and explored while in others it is still an understudied concept. In assessing resilience, the emphasis is usually on strengths with modellers moving away from vulnerability models to focus on trumps in cases of adversity (Van Breda, 2001). The core characteristics of resilience in a resilience framework are identified as diversity, spare capacity and organizational/structure. Diversity is proposed as the first principle for enhancing energy resilience and is also a defining characteristic of energy security.

Spare capacity is identified as a metric for energy resilience but its inclusion is generally not as a primary characteristic (Molyneaux *et al*., 2016). Spare capacity is a measure of energy security and has been used by economists in the calculations of adequate levels of reserve capacity to guard against energy disruption. Structure is presented as an important characteristic of energy resilience by the identification of frameworks to facilitate resilience through organisation to plan/prepare, absorb, recover and adapt (Roege *et al*., 2014) and the need to monitor system boundaries to facilitate flexible response to unexpected fault (Arghandeh *et al*., 2016).

Measuring progress toward a more resilient energy infrastructure requires developing and deploying metrics that can be used to assess planning, operations, and policy changes for energy infrastructure. A resilience metric framework is defined as the probability of a consequence given a threat" (Watson *et al*, 2014). In the context of this study, consequence X is the performance of the energy system while Y are threats such as fuel shocks and climate change.

2.2.2 System Variables

In dynamical terms, a system is defined by its state variables and it is the relationships among them that is of central interest. These relationships together with effects of external drivers are responsible for system changes (Walker et al., 2012). External variables are those within the scale of analysis that are not considered to be part of the system and are not affected by what happens within the system. External variable in this analysis comprise oil price shocks while electricity price is an internal variable.

2.2.3 Oil Shocks

Electricity generation that relies on imports of fuel from other countries will have implications for the electricity system's performance. Oil is arguably the most essential commodity in the modern industrial economy. As an energy source, oil is used for electricity generation and to a lesser extend for heating and cooking. Oil shocks are usually defined in terms of price fluctuations which may emanate from changes in either supply of or the demand for oil. There have been three oil price shocks to date: 1973-74, 1979-80 and 1990 (Wakeford, 2006). The three incidences involved at least doubling of the oil price within a year or two. Such cases of oil shocks can cause severe effects in electricity generation especially for countries that import oil.

2.2.4 Electricity Price

Electricity price represents the capacity of the system to adjust to change. In this sense, it can be considered to be predictive of energy resilience. In economics, change in price is usually measured when assessing the impact of independent variables on price. In electricity generation, historic and structural factors need to be taken into account if price is to represent the adaptive capacity. In the analysis, the weighted average price will be used. The industry price has been found to be the most appropriate measure of price to eliminate network costs and regulatory inconsistencies. Weighted average price provides more information about the state of the system during the energy shock than do other measures (Molyneaux *et al*., 2016).

2.3 Empirical Review

Several analyses on energy resilience by Roege *et al*., 2014 used a disaster resilience framework to identify four critical components to resilience; namely plan/prepare, absorb, recover and adapt. Sharifi and Yamagata, 2015 proposed a similar framework in research on urban energy resilience as that proposed by Roege *et al*. Arghandeh *et al*, 2016 in their definition of energy resilience for power networks provide a clear divide between the system characteristics of adaptive capacity and organizational structure to monitor and respond. IEA's Measuring Short Term Energy Security report, identifies 44 metrics to assess energy security including 22 for resilience (10 associated with import point for each fuel into a country; 6 with diversity of supplier; 3 with stock levels of crude oil, petroleum and natural gas; and one each measure flexibility of petroleum refining, natural gas intensity, and volatility of hydro power production). The metrics are assessed through subjective measures for representation of low, medium or high levels of resilience so that country profiles of energy security for risk and resilience can be established (IEA, 2011).

The interconnection between fuel systems affects the ability of state based electricity generators to respond to energy shocks. The price that emerges from each system reflects its dynamic nature. Molyneaux *et al*., 2016 attempted to measure resilience in energy using empirical analysis. Empirical analysis attempts to include the resilience metrics proposed by other researches to measure resilience. Apart from price, policy mechanisms were found to exacerbate energy crisis in the United States.

The study also demonstrates that a lack of spare capacity within fuel systems constrains responses that can isolate and contain the original problem. The study by Molyneaux *et al*., provides empirical evidence for the inclusion of spare capacity and structure, as a proxy for diversification, as metrics of resilience.

2.4 Conceptual Framework

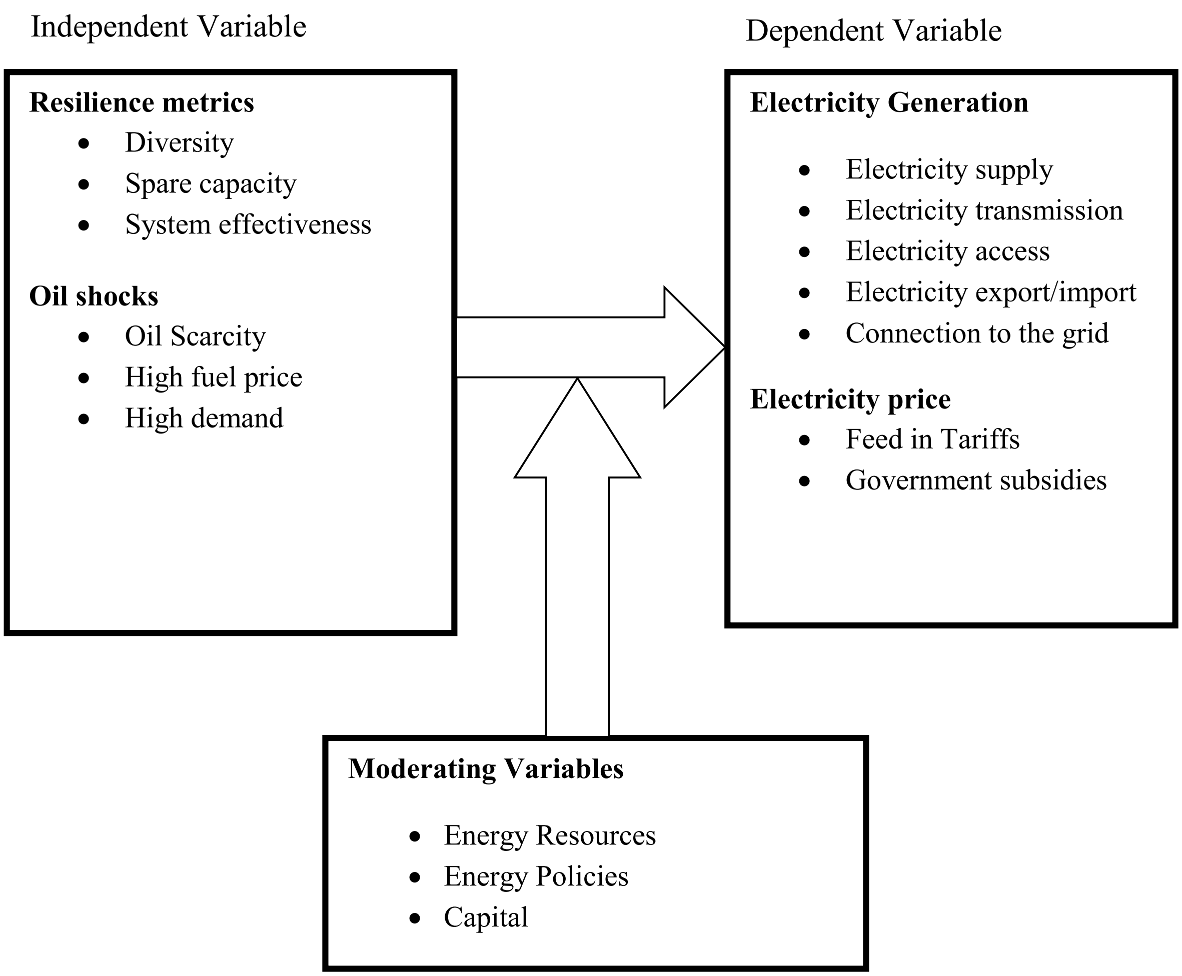

Figure 1: A conceptualized framework on the link between fast variables and electricity generation

The conceptual framework in figure 2 above shows that fast variables (oil shocks) and resilience metrics affect electricity generation and electricity price. The fast variables, resilience metrics and electricity generation are moderated by energy resources, energy policies and capital.

2.5 Critique of the Literature

The few available studies on energy resilience tend to greatly rely on qualitative approaches in assessing resilience in energy systems. The studies are based on discussions and explanations of different resilience metrics using expert opinions that are usually subjective. In majority of the studies, only attempts to propose conceptual frameworks and metrics for measuring energy resilience are discussed and no efforts are made to verify the proposed metrics and frameworks for real case scenarios.

2.6 Research gaps

Research on energy resilience lags behind in terms of quantitative measures and therefore lacks empirical evidence. A study presented in this review remains the only first step on the path to providing quantifiable evidence for metrics of energy resilience. There are also limited case study examples to draw conclusions from. This study will therefore seek to build on this first attempt and create more insights into empirical evidence for energy resilience while presenting case study scenario for Kenya.

From available literature, it is evident that resilience in energy systems is a concept that is still at an early stage and warrants further investigation. Existing knowledge presents metrics that suggest the existence of a link between some variables and energy resilience, however these are not empirically determined. Though not fully conclusive, a case study in the United States seems to be a breakthrough to quantitative measures in assessing resilience. However, there is still room for more empirical evidence on resilience and this study will attempt to address this by extending it to the case of Kenya.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The methods employed in this research are centred at establishing the significance of electricity price, global oil prices, diversity, spare capacity, system structure in quantifying resilience in electricity generation in Kenya when subjected to both internal and external stress.

3.2 Research Design

The researcher adopted a quantitative design method through the use of correlation and multiple linear regression models to find the existence of relationships between variables. Qualitative aspects of resilience were also analysed. This research therefore employed both quantitative and qualitative design methods. The design is ideal for this study because it seeks to empirically establish the relationship effects of different variables in predicting resilience in electricity generation.

3.2.1 Time Series Analysis

An additive time series is composed of the trend, seasonal and random components as shown I equation 1 below.

$$Y_t = S_t + T_t + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where,

Y_t: Time series of a variable Y

T_t: The trend component

S_t: Seasonal component

ε_t: Random component

The values for the trend are determined by calculating the centred moving averages of span 12, i.e averaging the observed data (x) at times 1 to 12 as given by equation 2.

$$T_t = \frac{1}{12}(x_1 + x_2 + x_3 + \cdots + x_{12}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

The seasonal effects are estimated according to equation 3. For an additive time series, the seasonal effects are adjusted so that their average becomes 0.

$$\hat{s}_t = \frac{(x_t + x_{t+12} + x_{t+24} \ldots)}{N} \ldots\ldots\ldots\ldots\ldots..(3)$$

The random component is the remainder of the time series after extracting the trend and seasonal components according to equation 4.

$$\varepsilon = Y_t - T_t - S_t \text{ ………………… (4)}$$

Time series decomposition is easily executed in R. R software has established itself as the choice for many researchers especially for advanced algorithms (McLeod, 2011).

3.2.2 Diversity

For the purposes of this analysis, diversity is taken to be a measure of possible energy alternatives. Simpson's Diversity Index given by equation 5 below is a measure of diversity that takes into account the number of energy types present and also considers the relative abundance of each energy type.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right) \text{ …………………………… (5)}$$

Where,

D = diversity

n = the total number of kwh generated from each energy type

N = the total number of kwh generated from all available energy types

The value of D ranges between 0 and 1 with 1 representing infinite diversity while 0 indicates lack of diversity.

The Simpson's Diversity Index is also referred to as a dominance index because it gives more weight to dominant species. According to this index, as species evenness increases, diversity increases. The assumption made is that a few rare energy types which have fewer representatives will not affect the diversity.

3.2.3 Spare Capacity

Spare capacity is calculated as the difference between the amount of electricity generated in a year, and the amount of electricity that could be generated at full capacity as shown in equation 6 below (Molyneaux *et al.*, 2016).

$$SP = (\textstyle\sum_{i=1}^{n} \left(\left((GW_i * hours) * CF_i \right) - GWh_i \right) \right) / GDPR \text{ ………………… (6)}$$

Where,

SP = Potential energy available for use in economy

GW_i = Installed capacity in millions of kilowatts using fuel type i

$hours$ = 8760 hours is generally assumed in estimations of total annual capacity

CF_i = Capacity factor: Maximum proportion of total generation possible from installed plant for fuel type i

GWh_i = Electricity generated in millions of kilowatts from fuel type i

$GDPR$ = Real Gross Domestic Product in $ millions

i = Fuel types: Wind, solar, geothermal, hydropower, thermal

Capacity factor

The capacity factor of a power plant is the ratio of the actual energy output (in kwh) of the power plant over a certain period of time to the total energy that would be produced if the plant operated all the time, with no need for plant maintenance or output reductions (Fernando et al, 2013). This can be determined by the plant's designed (installed power) and its operating features as expressed by equation 7.

$$CF = \frac{(E*100)}{P*H} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

CF Capacity factor (%)

E Energy produced over a certain time interval (kWh)

P Installed power (kW)

H Number of hours in the same time interval (h)

3.2.4 System Structure

In measuring structure, the following two important metrics will be considered; the efficiency of generation, and electricity imports. The efficiency of generation measures the effectiveness of the system and is represented by losses in the grid.

A fast insight into evidence of fuel importation for electricity generation is where the total consumption of each fuel is greater than the total production of that fuel.
The import metric is expressed by equation 8 below.

$$PEI = \left(\psi * \frac{-EIM+EEX}{TEC}\right) + \left(\theta * \frac{-EIM+EEX}{TEG}\right) \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where,

PEI Proportion of electricity Exported/Imported

EIM Electricity Imports in GWh

EEX Electricity Exports in GWh

TEC Total Electricity Consumed in GWh

TEG Total Electricity Generated in GWh

ψ Net import indicator: If $(-EIM + EEX)$ < 0, then $\psi = -1$, else $\psi = 0$

θ Net export indicator: If $(-EIM + EEX)$ > 0, then θ = -1, else $\theta = 0$

3.2.5 Regression analysis

The regression model will be used to form a relationship between weighted average electricity prices and resilience metrics. In this model, the weighted average electricity price is the dependent variable while resilience metrics are independent variables as expressed in equation 9.

$$Y_s = \beta_0 + \beta_1 X_{1S} + \beta_2 X_{2S} + \ldots + \beta_K X_{ks} + \varepsilon_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Where,

Y_s weighted average price of electricity (independent variable)

β_0 intercept of the weighted average price

β_K coefficients of X_{ks}

X_{ks} variable of resilience metric

ε_s random error in the weighted average price

The decision to select price as the predictand in this model is informed by the analogy that price can represents the capacity of the electricity system to adjust to change and therefore it can be considered to be indicative of energy resilience. The weighted average price was calculated from the actual prices according to equation 10.

$$Wtd.Avg. = (P_1 S_1 + P_2 S_2 + P_3 S_3 + \cdots P_n S_n)/T_s \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

Where,

$Wtd.Avg.$ – Weighted average price

P_n – Actual price in the n[th] month in KES/kWh

S_i – Total electricity sales in the nth month in kWh

T_s – Total sum of electricity sales for the n months in kWh

3.2.6 Correlation Analysis

The relationship between electricity price and electricity generation was determined by carrying out correlation analysis according to the Pearson's correlation coefficient given by the following relation

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}[(x_i-\bar{x})(y_i-\bar{y})]}{\left[\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2 \cdot \frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y})^2\right]^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where, r_{xy} is the correlation between electricity price and electricity generation

x_i , y_i are the individual data points for electricity price and electricity generation respectively

$\bar{x}$, $\bar{y}$ are the mean of electricity price and electricity generation respectively

n is the total number of data records

3.3 Data

The data used in this study was mainly primary data obtained from the Kenya National Bureau of Statistics (KNBS) and data archived by CEIC Data (https://www.ceicdata.com/en), Stima (https://stima.regulusweb.com/), Macro Trends and Trading Economics. The data consisted of electricity generation capacity by source, electricity installed capacity by source, electricity price components, electricity importation, Real Gross Domestic Product (GDPR), electricity sales, electricity consumption, electricity transmission and distribution losses, global oil prices and average precipitation data over the country.

Table 1 summarizes the various datasets, frequencies and their source. The study did not utilize primary data from interviews and questionnaires and therefore no sampling methods were used.

Table 1: Description of data used in the study

Parameter	Frequency	Span	Datasets	Data points	Source
Electricity generation	Monthly	09.2005-03.2018	4	604	KNBS (CEIC)
	Annually	1980-2016	4	144	KNBS (CEIC)
Installed capacity	Monthly	09.2005-03.2018	4	604	KNBS (CEIC)
	Annual	1980-2016	4	144	KNBS (CEIC)
Electricity price	Monthly	11.2008-03.2018	8	808	Stima (Rugus)
Electricity Imports	Monthly	09.2005-03.2018	4	604	KNBS (CEIC)
	Annual	1980-2016	1	36	KNBS (CEIC)
Electricity sales	Monthly	10.2005-03.2018	1	150	KNBS (CEIC)
Electricity consumption	Yearly	1980-2017	2	74	KNBS (CEIC)
Transmission and distribution losses	Monthly	10.2005-06.2017	1	141	KNBS (CEIC)
	Annual	1980-2016	1	36	KNBS (CEIC)
Global Oil prices	Monthly	01.1980-03.2018	1	447	Wessex Texas Intermediate (WTI), Macro trends
Precipitation	Monthly	01.1970-12.2015	1	540	Trading Economics
Total			**34**	**4332**	

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Inter-Annual and Intra-Annual Variation in Electrical Energy Generation Mix.

In this section, findings, discussions and graphical presentations in form of annual time series and annual cycles of electricity generation capacity and installed capacities are provided. Discussions of installed generation plants are also included in this section.

4.1.1 Inter-Annual Variation in Electrical Energy Generation

Kenya's electricity generation industry is mainly dominated by the government with the state owned Electricity Generating Company (KenGen) accounting for 71.1% of the effective generation capacity. Independent Power Producers (IPPs) account for only 26.1% of total generation eliciting concerns regarding the competitiveness of the electricity generation industry in the country.

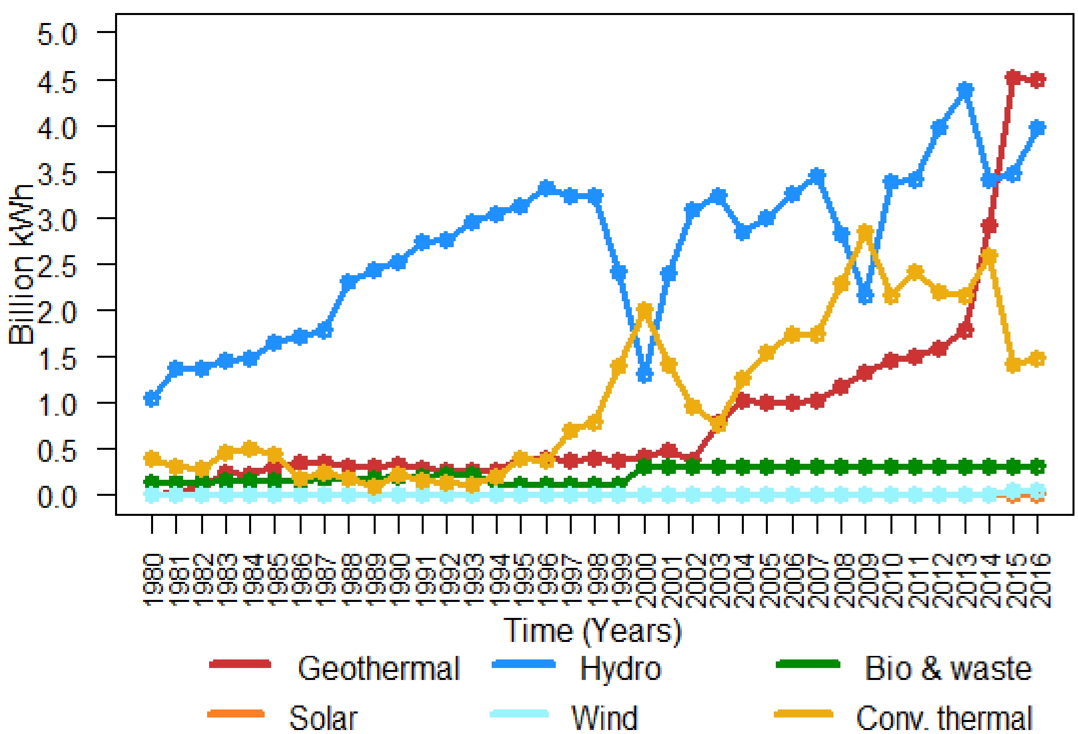

Figure 4.1: Trends in the net electricity generated by individual local sources

Kenya has various energy sources with only a few contributing significantly to addressing the energy needs of the country. Figure 4.1 presents the contribution of each of the available energy sources by the quantity of its net electricity generated. Hydropower has dominated the electricity sector since the year 1980, contributing more than 1 billion kilowatt hours throughout this period. From figure 4.1, it can be deduced that conventional thermal electricity is used as a contingency plan in the event that the generation from the renewable sources is low. This is evidenced by the troughs in the hydropower graph being filled by peaks in the conventional thermal electricity curve. Generation from fossil fuels has continued to decrease as a result of increase in geothermal generation.

Geothermal has been on the rise in recent years and has since surpassed hydropower as the major contributor to electricity production. In the years 2015 and 2016, generation from geothermal was 4.5 billion kilowatt-hours compared to 3.5 and 4.0 billion kilowatt-hours for hydropower over the same period respectively. There has been continued decrease in hydropower generation from the year 2012 due to poor hydrology. Other contributors to the Kenya electricity mix include, biomass & waste, solar and wind. Contribution from solar, wind and biomass has remained relatively low (less than 0.5 billion kwh) although there has been slight improvement in wind power in the two latter years.

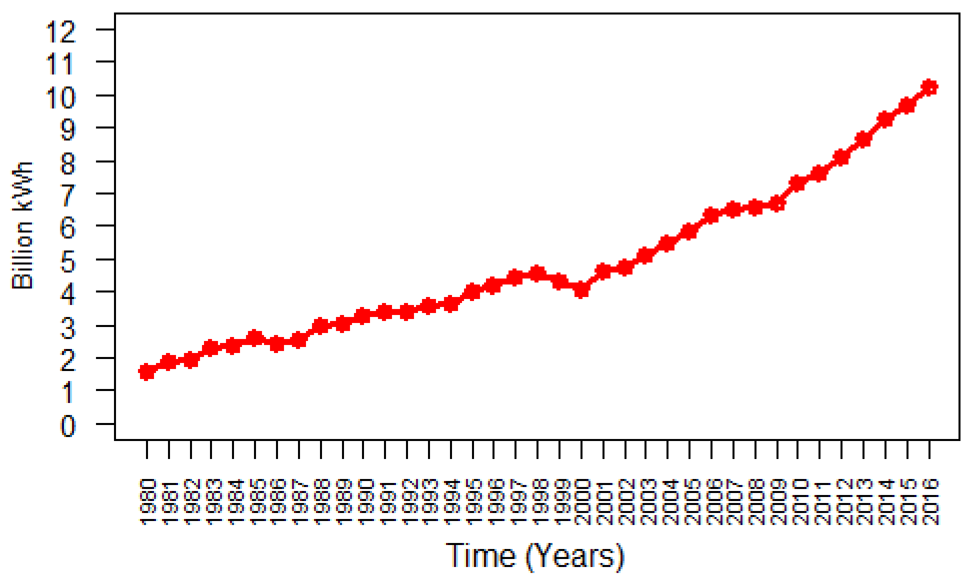

Figure 4.2: Total local net generation in billion Kilowatt-hours

Expansion of geothermal in Kenya has seen an increase in the generation capacity as depicted in figure 4.2.

However, a significant amount of this generation has also been contributed by conventional thermal sources especially between 2006 and 2014, the period in which there was relatively low generation from hydropower sources. A sharp rise in geothermal generation capacity between 2013 and 2016 marked a decrease in conventional thermal electricity generation. Majority of the electricity produced in Kenya is from renewable sources that has been dominated by hydropower for long periods prior to the recent expansion of geothermal power. Currently renewable sources account for about 86% of total electricity generated in Kenya. Between the years 1980 to 2003, hydropower contributed more than 75% of total electricity generated from renewable energy (figure 4.3).

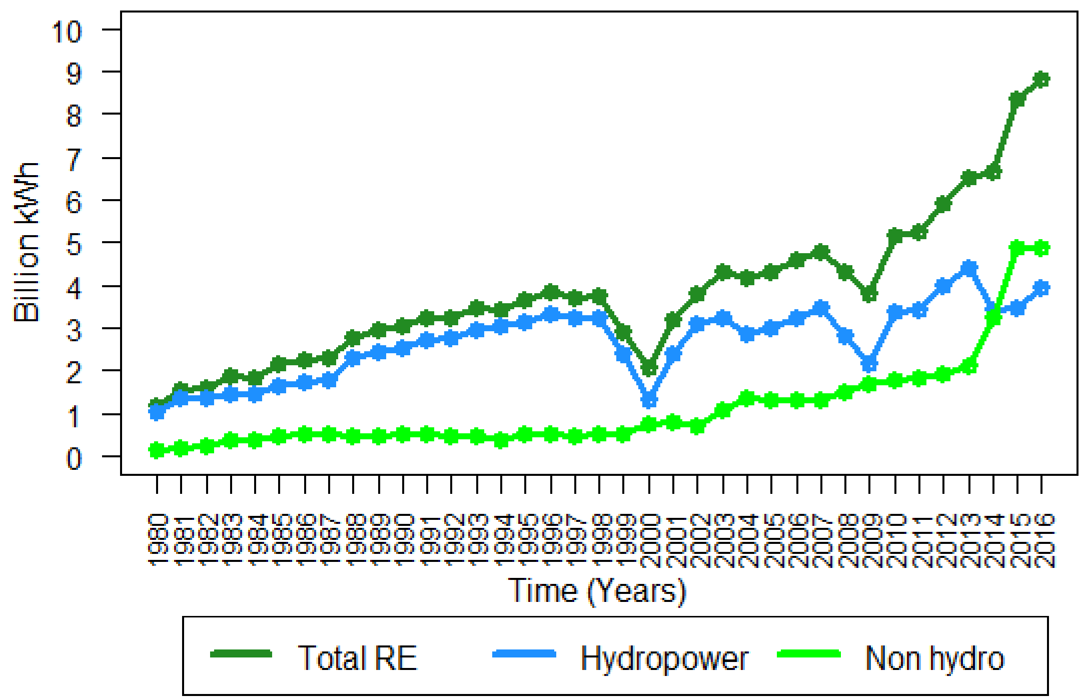

Figure 4.3: Total electricity net generation from local RE, hydro and non-hydro sources

Currently, hydropower accounts for about 45% of total renewable energy generation while geothermal has taken the lead at about 51%. Geothermal energy seems to be critical to the future of Kenya's electricity sector and this may be just what Kenya needs to overcome the uncertainties surrounding hydropower sources in the wake of climate change extremes. New entrants such as wind power and solar into the generation mix also spells an encouraging future in the Kenya's electricity sector and may boost the resilience of this sector to adverse climate change effects and volatility in the conventional energy sources. Renewable energy sources exhibit a linear inter-annual pattern that is as a result of increased investment into renewable energy technologies especially geothermal (ERC, 2015).

4.1.2 Intra-Annual Variation in Electrical Energy Generation

Seasonal variation in electricity generation is influenced by a number of factors that include variation in demand patterns during the year and changes in weather pattern. Demand can be influenced by weather conditions or other events that are determined by human activities. Demand peaks and troughs need to be met by different generation characteristics hence variations in the annual cycle of electricity generation. Whereas weather conditions influences electricity demand and hence generation, this might not be the case in Kenya. Being within the tropics, Kenya does not experience extreme cold and hot conditions during winter and summer respectively that usually trigger a huge demand of electricity for heating and cooling. Weather conditions affect the generation of electricity from the production point of view seen in the manifestation of poor hydrologic conditions that impact hydropower production.

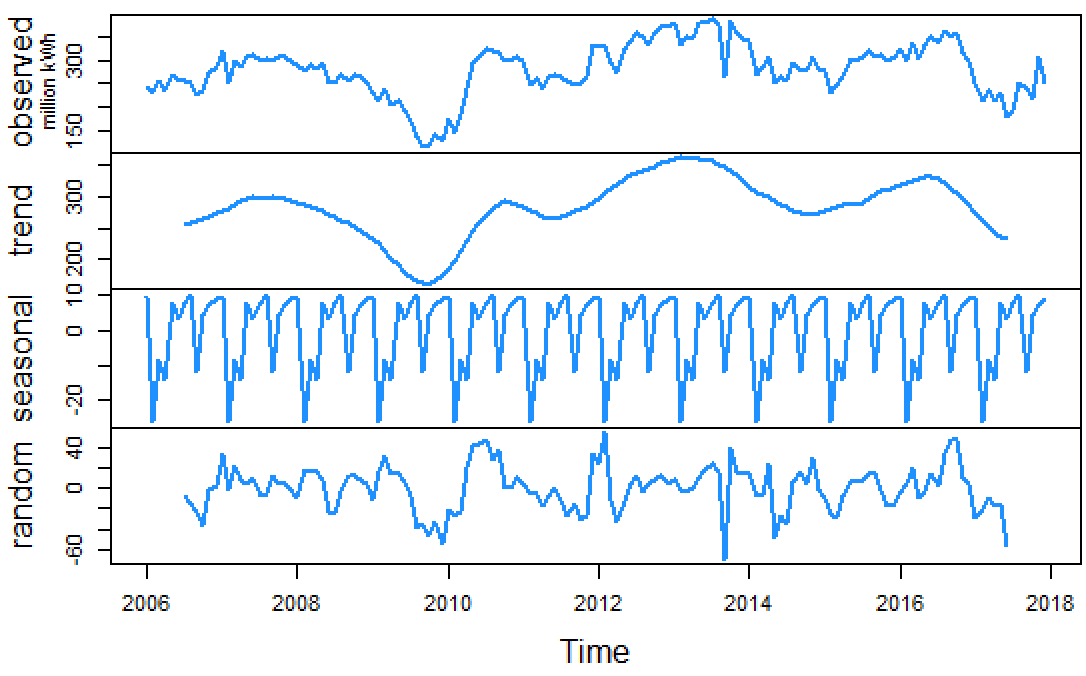

Figure 4.4: Decomposition of additive time series for hydropower generation

The seasonal factors estimated from the data in figure 4.4 show that the highest peak is in the month of August and the lowest trough occurring in February.

The seasonal variation in hydropower generation depicts a bimodal pattern with two peaks in May to August and October to January while February to April and the month of September form the troughs. It is noted that the May to August peak occurs immediately after the long rains season while the October to January peak occurs during the short rains season. The troughs are experienced during relatively drier seasons. The trend in figure 4.4 does not follow any particular pattern indicating high volatility in hydropower generation mainly due to variability in hydrologic conditions. This is also indicated by the random component which shows high variations of up to -60 from the trend. Geothermal generation indicates an increasing trend but the seasonal component is irregular with no distinct pattern as shown in figure 4.5. However, smoothening the time series shows a tri-modal seasonal pattern with peaks in July, September to November and January while a prolonged trough occurs from February to June.

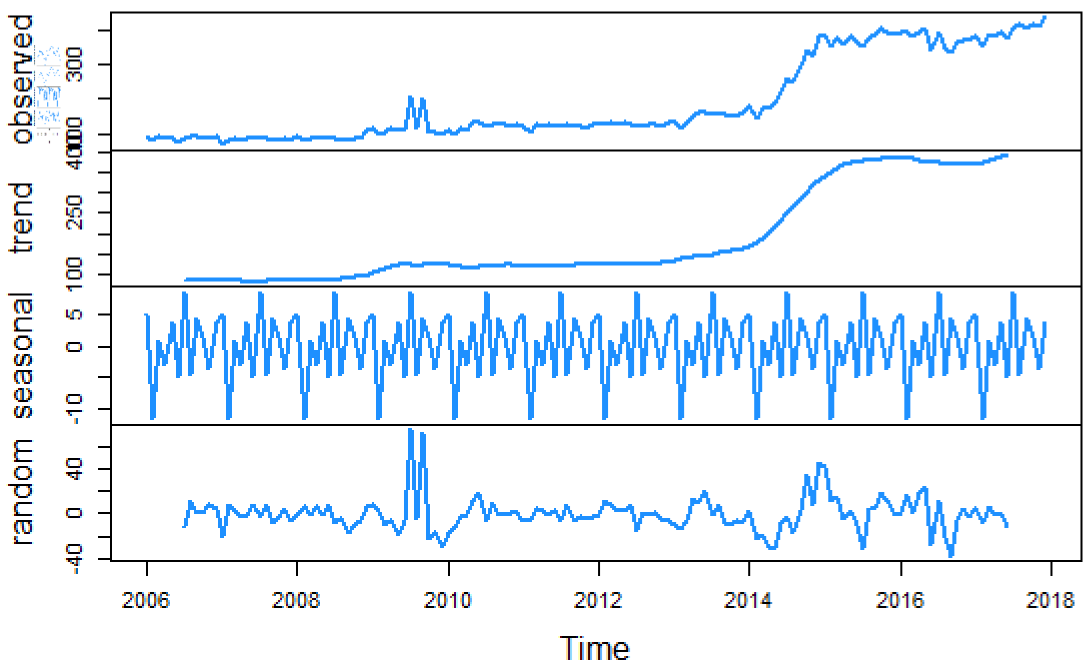

Figure 4.5: Decomposition of additive time series for geothermal generation

The smoothened seasonal time series is shown in figure 4.6. Geothermal generation is independent of weather conditions and this seasonal variation may be due to changes in demand driven by different activities over the course of the year.

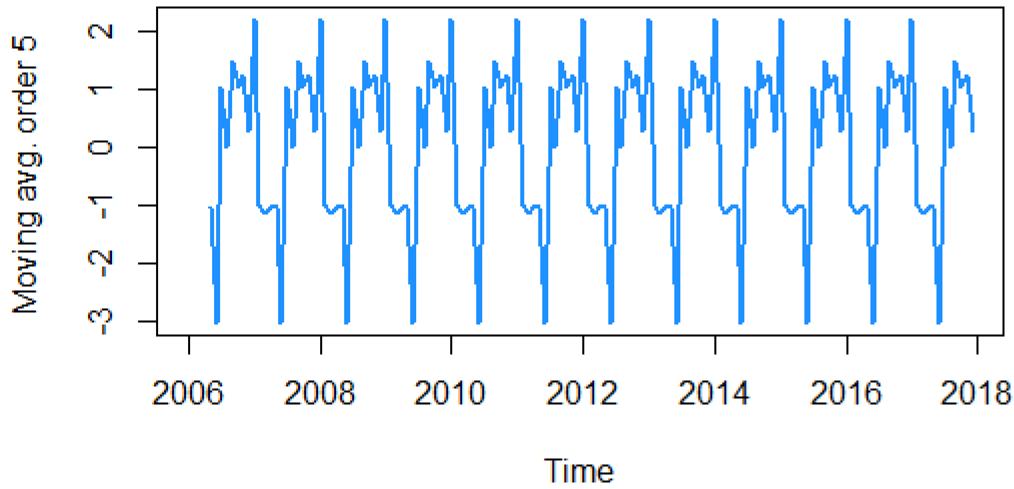

Figure 4.6: Simple moving averages of order 5 for geothermal seasonal component

Thermal generation exhibits seasonality in a tri-modal pattern as shown in figure 4.7 but in the counter-direction to that of hydropower. The peaks occur in the months of March, August and October while November to February form the lowest trough. Other troughs occur in April, July and September. Thermal generation is deployed to fill the deficiency left as a result of hydropower troughs. Thermal electricity generation is not affected by environmental conditions thus offering a suitable alternative for emergency power.

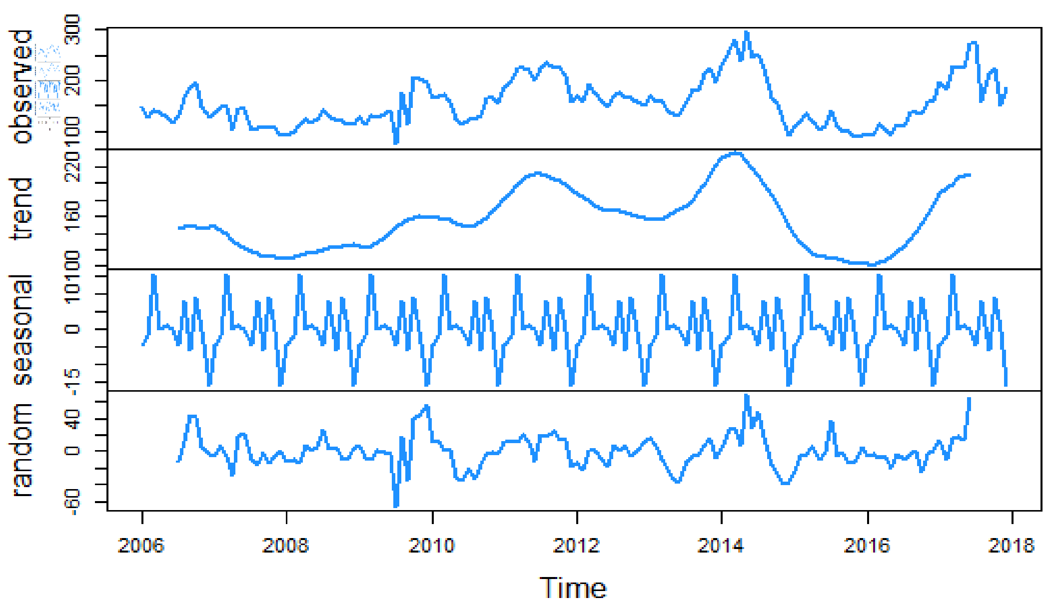

Figure 4.7: Decomposition of additive time series for thermal generation

Electrical energy generation in Kenya has been on the increasing trend (figure 4.8) mainly in response to increasing demand. This increase has been made possible by corresponding increases in geothermal generation and new ventures into wind energy. Hydropower continues to decline, succumbing to climatic changes while the future of thermal generation remains uncertain. The seasonal component for total electrical energy generation also exhibits seasonality with a tri-modal pattern whose distinct peaks occur in the months of March, August and October (figure 4.8). The highest peak occurs in March while the lowest trough is in the month of December signifying demand surges and demand slump in March and December respectively.

With respect to the trend, the random component is for most of the period in the negative phase which represents the instantaneous random decline in electrical energy generation. This decline is seen to go as low as -80 at some point in September 2013 which is as a result of decrease in hydropower generation over the same month as shown in the hydropower time series in figure 4.4. The decrease could have been due to depressed hydrologic conditions. Other than this extreme instance, random variations are within 20 to -40 range from the trend. These random fluctuations are the consequences of periodic fluctuations in generation which may not be planned but resulting from factors such as mechanical breakdown of generators and scheduled or unscheduled maintenance.

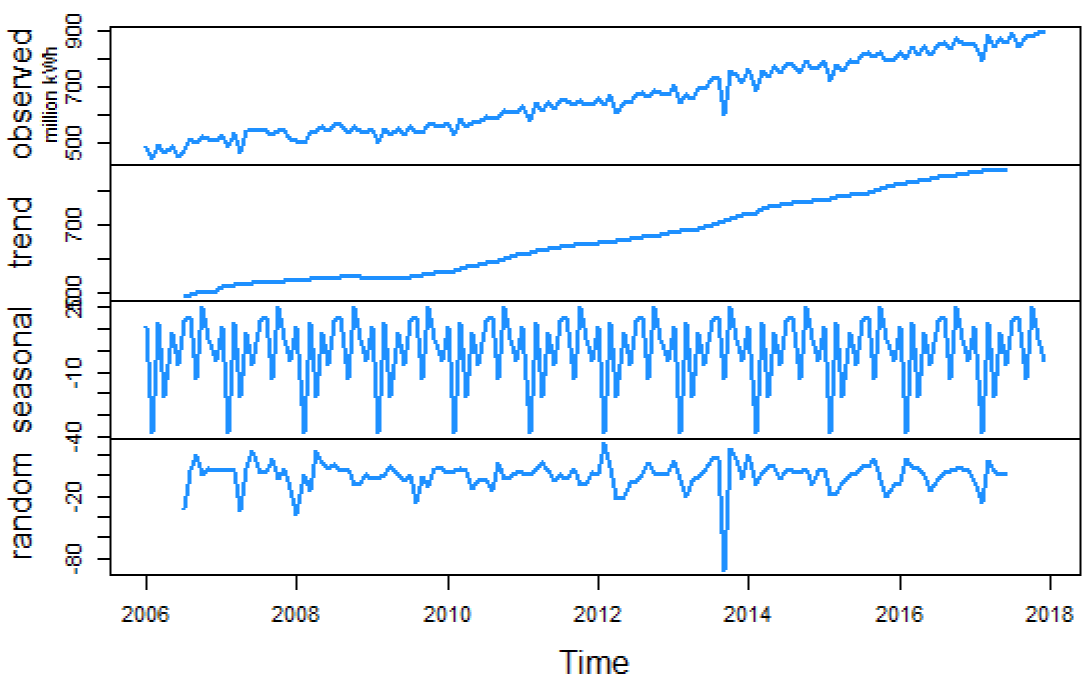

Figure 4.8: Decomposition of additive time series for total electrical energy generation

4.1.3 Installed electricity generation capacity

Whereas electricity generation is the total amount of electricity generated over a specified period of time, installed electricity generation capacity comprises the maximum output of electricity that can be generated by electric power plants, also full load rating of a generator. From figure 4.9 the net installed generation capacity has increased from just about 0.6 GW in 1980 to about 2.2 GW in 2016. Hydropower, geothermal and combustible fuels account for about 99% of the installed capacity with capacities of 0.8 GW, 0.64 GW and 0.79 GW respectively in the year 2016. Wind accounted for only 0.026 GW in that year which was quite insignificant compared to the three other sources.

The graph for hydropower exhibits a unique pattern that resembles a staircase structure (figure 4.9). This impression is as a result of increasing the installed capacity at some point which then remains unchanged for quite a while before expanding it again. This pattern of expansion is initially seen to occur after every seven years for the period 1980 to 2007.

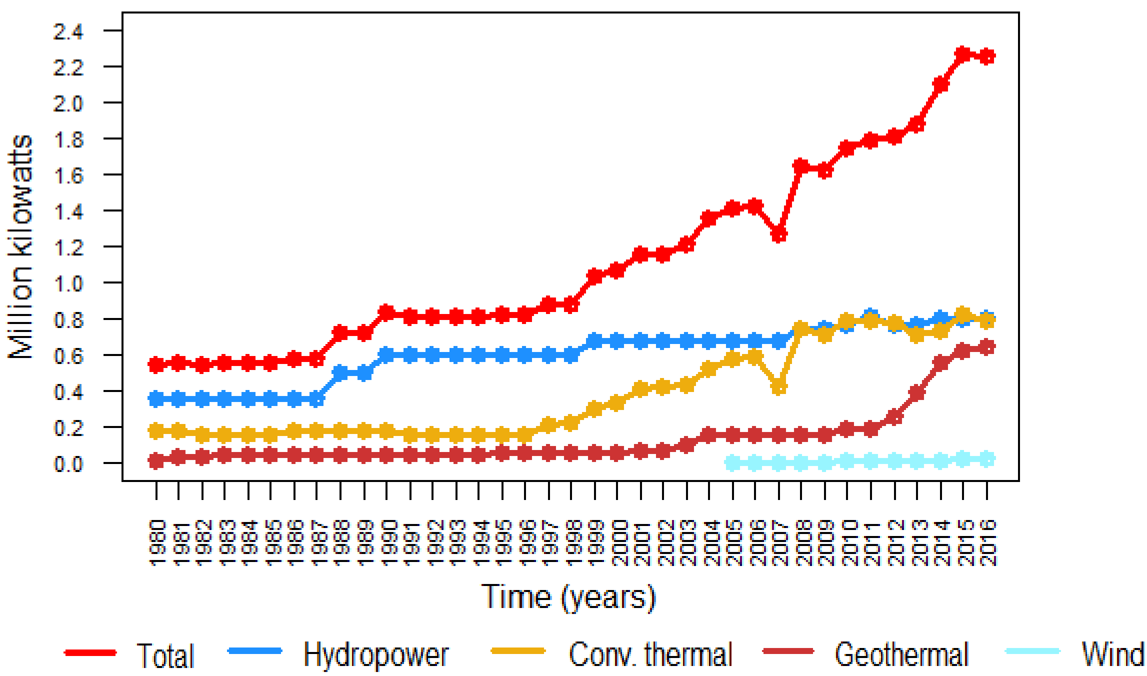

Figure 4.9: Generation capacity of different electricity sources

However, with increasing demand for electricity, the expansion of hydropower has been frequent, occurring almost every year from 2008 to 2016.

On the other hand, the installed capacity for geothermal has been increasing from the year 2000 with a sharp rise in 2013 to reach a peak of 0.64 GW in 2016 (figure 4.9). Combustible fuels plants remain an integral part in the total installed generation capacity of Kenya accounting for 35% of the installed capacity. There was a decline in the installed capacity of combustible fuels plants between the years 2007 and 2010. It is observed that this decline coincided with an increase in hydropower and geothermal installed capacities. This trend is as a result of an attempt to decommissioning conventional source power plants in favour of renewable energy sources in Kenya (ERC, 2015).

Wind power has not been a significant contributor to electricity generation in Kenya, as shown in figure 4.9. In the recent years Kenya has stepped up the pursuit for wind energy resource for purposes of electricity generation. This has seen an increase from 0.005 million kilowatts in 2010 to 0.026 million kilowatts in 2016. Kenya has only one wind Power station connected to the national grid - Ngong power station which is located on the northern part of Ngong hills near the capital city, Nairobi. Initially, this power station was generating 0.005 million kilowatts from six wind turbines that were commissioned in 2009.

Electricity generation is always lower than the installed capacity if installed capacities were to be expressed in terms of kWh. Installed capacity and generation have linear relationship because the installed capacity determines how much power a plant is capable of generating as it is impossible to generate more than what is installed. However, it is not always the case that an increase in installed capacity will correspond to an increase in generation unless all other factors affecting generation remain constant. In many cases as is with the case of Kenya, generation could be much lower than installed capacity. Quantifying the electricity situation in a country ought therefore not be based on installed capicities alone.

4.1.4 Installed Electric Power facilities in Kenya

According to the analysis above, it is evident that Kenya has varied electricity sources. Electricity generation is managed by KenGen, a state owned power utility. However, there exists several Independent Power Producers (IPPs), Emergency Power Producers (EPP) and the Government of Kenya Rural Electrification Program. By 2017, there existed a total of 36 power generator facilities in Kenya according to energy data by the World Bank and the International Finance Corporation (World bank group) and the Energy Regulatory Commission (ERC). Of these, 23 are operated by KenGen, there are 9 IPPs, 1 EPP and another 3 under the Kenya Rural Electrification program.

Hydropower

Table 2: Hydropower generator stations and their capacities, 2016

Power Generator	Installed Capacity	Effective Capacity	Company
Gitaru	225 MW	216 MW	KenGen
Kamburu	94.2 MW	90 MW	KenGen
Kiambere	168 MW	164 MW	KenGen
Kindaruma	72 MW	70.5 MW	KenGen
Masinga	40 MW	40 MW	KenGen
Sondu Miriu	60 MW	60 MW	KenGen
Tana	20 MW	20 MW	KenGen
Turkwel	106 MW	105 MW	KenGen
Sangoro	21 MW	20 MW	KenGen
Small Hydros	13.4 MW	13.2 MW	KenGen
Imenti Tea Factory hydro	0.3 MW	0.3 MW	Imenti Tea Factory
Gikira small hydro	0.514 MW	0.514 MW	IPP

Further breakdown indicates that there are a total of 12 hydropower plants in Kenya, 10 of them operated by KenGen and a micro hydro plant owned by Imenti tea factory. The largest hydropower plant by installed capacity and effective capacity is the Gitaru hydropower station on the Tana River with installed capacity of 225 MW and effective capacity of 216 MW as shown in table 2.

Geothermal

The single largest geothermal power station is Olkaria IV which consists of two plants that were commissioned in 2014 and 2015 with a total installed capacity of 140 MW (Table 3). With a combine installed capacity of 280 MW this is also the single largest geothermal plant in the world from a single site.

Table 3: Installed and effective capacities of geothermal plants

Power Generator	Installed Capacity	Effective Capacity	Company
Olkaria I	45 MW	44 MW	KenGen
Olkaria II	105 MW	101 MW	KenGen
Eburru Hill	2.5 MW	2.2 MW	KenGen
OW37 Olkaria Mobile Wellheads	5 MW	2.2 MW	KenGen
OW43 Olkaria Mobile Wellheads	12.8 MW	12.8 MW	KenGen
OW914 and OW915 Olkaria Wellheads	37.8 MW	37.8 MW	KenGen
Olkaria IV	140 MW	140 MW	KenGen
Olkaria I 4 & 5	140 MW	140 MW	KenGen
OrPower 4 - Geothermal I, II & III	110 MW	110 MW	IPP

Others include, Olkaria I which was the first geothermal power plant in Africa with an installed capacity of 45 MW. Olkaria II geothermal plant was commissioned in 2010 and has an installed capacity of 105 MW. There also exists Olkaria Wellhead 37 (OW37), Olkaria Wellhead 43 (OW43) and Olkaria Wellhead (OW914 and OW915) with installed capacities of 5 MW, 12.8 MW and 37.8 MW respectively as shown in table 3. Eburru hill located northwest of Lake Naivasha has installed capacity of 2.5 MW and effective capacity of 2.2 MW of geothermal power. All these geothermal power plants are owned and operated by KenGen apart from OrPower 4 which is an IPP.

Other Power Generators

Independent power producers mainly operate thermal power plants with the exception of Mumias Sugar Company and Imenti Tea Factory which run biomass and hydro power plants respectively as shown in table 2 and 4. Kenya Power, a utility whose core mandate is to plan for sufficient electricity generation and retail electricity to consumers purchases electricity from six IPPs; Tsavo Power Company Limited (TPC), Iberafrica Power (EA), Rabai Power Limited, OrPower4 Inc. (OrPower4), Mumias Sugar Company Limited and Imenti Tea Factory Small hydros. The 26 MW biomass plant is a bagasse based cogeneration project owned by Mumias Sugar Company Limited. The plant generates 35 MW of electricity and uses about 10 MW and sending the remaining 25 MW to the national grid. KenGen owns a significant number of thermal power plants (5) while all Emergency Power Producers are thermal. Thermal power plants are highly reliable and their non-intermittency nature informs the decision to have them as EPPs. Kipevu III comprises seven diesel engines and is the largest diesel plant in the region.

Table 4: Other electricity generator stations

Power generator	Installed Capacity	Effective Capacity	Type	Company
Embakasi gas turbines	60	54	Thermal	KenGen
Garissa & Lamu	5.7	5.1	Thermal	KenGen
Kipevu I Diesel	72.5	52.3	Thermal	KenGen
Kipevu III Diesel	120	115	Thermal	KenGen
Ngong	25.5	25.5	Wind	KenGen
Aggreko-Embakasi thermal	40	40	Thermal	EPP
Thika Power	87	87	Thermal	IPP
Tsavo Power	74	74	Thermal	IPP
Rabai Power	90	90	Thermal	IPP
Iberafrica I&II Power	108.5	108.5	Thermal and Geothermal	IPP
Aggreko energy to Kenyan Market	30	30	Thermal and Geothermal	EPP
Aggreko-Naivasha thermal	150	150	Thermal	EPP
Mumias - Cogeneration	25	21.5	Biomass	IPP
Triumph Diesel	77	77	Thermal	IPP
Gulf Power	80.32	80.32	Thermal	IPP

All the power facilities discussed above are connected to the national grid. However, under the Kenya Government Rural Electrification Program (REP), there is 18 MW thermal capacity, 0.569 MW of solar and 0.55 MW of wind that are off grid. The total off grid installed capacity stands at 19 MW with effective capacity of 15 MW.

4.2 Climate change and the electricity sector

The energy market is highly dynamic and it may not be easy to project future energy generation and demand for longer periods of up to 2050. However, climate change has occupied most talk about future energy scenarios with most emphasis being placed on renewable energy technologies as best solutions to tackle climate change extremes. While the electricity sector has been on the negative side of climate change talk constituting greenhouse gas emissions, it ought to be noted that different electricity generation technologies are also vulnerable to climate change effects. Hydropower is greatly impacted by reduction in river flows caused by decreased rainfall and enhanced evapotranspiration. Surface wind speed and its fluctuation influences the energy available in the wind while cloudiness affects energy produced by solar Photovoltaics (PV) systems.

The future of hydropower remains uncertain in the wake of increased ventures into non-hydro renewable energy. As a consequence of its vulnerability to climate change effects, talks on renewable energy hardly mention hydropower. The technology is also considered old and mature thus uninteresting. Despise this, hydropower together with geothermal remains the back born of renewable energy for grid based systems because of their ability to supply base load as opposed to wind and solar energy that are highly intermittent. This section therefore analyses the effects of climate variation on hydropower production. Climate extremes are presented through qualitative analysis of monthly rainfall data averaged over the whole country.

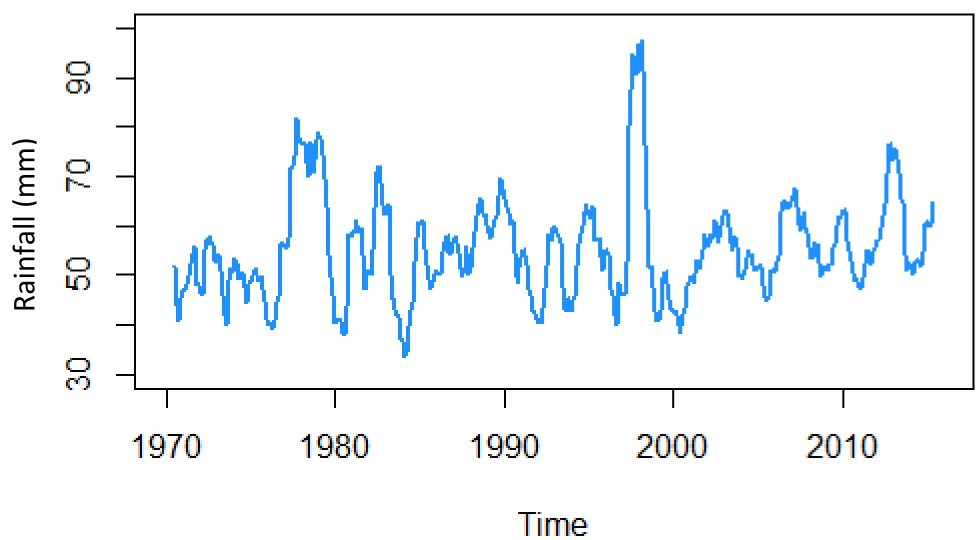

Figure 4.10: Trend component of average rainfall over Kenya

From figure 4.10, it is evident that rainfall does not follow any particular trend and is characterised by extreme highs and lows that are beneficial and detrimental to hydropower respectively. Climate change is likely to worsen this trend making rainfall more unreliable for hydropower than before.

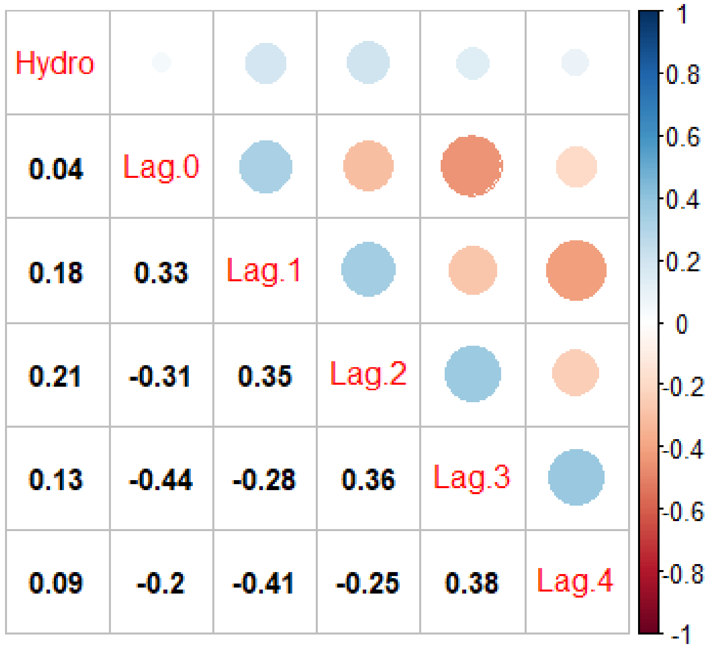

Figure 4.11: Correlation matrix of hydropower and rainfall at different lags

Kenya shall have to venture more into its geothermal reserves that is estimated to be about 10 GW and its vast solar and wind potential in order counter the struggling hydropower. The relationship between hydropower generation and rainfall in shown in figure 4.11. From the correlation matrix, hydropower and rainfall show no correlation at lag 0. The correlation improves at lag 1, lag 2 and lag 3 but diminishes at lag 4. At lag 0, rain that falls, however strong it may be, is used to replenish the water catchment area and little is left for surface runoff. Most, in fact all hydropower plants in Kenya are reservoir based thus respond to precipitation gradually as opposed to runoff river. Some are replenished by aquifers that take more time to refill. The correlation is therefore much improved at lag 2 (mid-season) because this is when almost all the catchment deficits have been replenished and the rainfall is contributing directly to the reservoir through runoff streams. At lag 4, the season is already over and the precipitation during that season has been exhausted.

From this analysis, it is evident that rainfall greatly impacts hydropower generation whose availability depends on the prevailing weather conditions which is as a result of the long term climate scenarios.

4.3 Resilience Metrics

Resilience metrics discussed in this section form the measures which determine electrical energy status in terms of generation, availability, affordability and sustainability. The three metrics are diversity, spare capacity and the system effectiveness. System effectiveness is represented by the Imports and efficiency metrics.

4.3.1 Diversity

Diversity is seen as a long time strategy of the energy systems because it allows high flexibility and adaptability. Diversity is important in energy policy and an important characteristic in energy supply security, efficiency, adaptability of the energy system and the environment. Increase in diversity of energy supply is beneficial for a system through extending choice and increasing competition (Liang-huey et al., 2011). From earlier discussions in this work, many of the trends show significant increase in renewable energy in Kenya relative to conventional energy sources. This is likely to signify increase in energy supply diversity and also increasing choice of energy and competition for supply. This assertion is confirmed by the results of the Simpson's Diversity index in table 5 and a visual impression of the results in figure 4.12. The Simpson's Diversity Index measures diversity on a scale of 0 to 1 with increasing diversity as the value approaches 1 and decreasing diversity as it tends to 0. Diversity in the Kenya's electricity sector exhibits annual variations with higher values in the recent years (2000 to 2016) and lower values between 1988 to 1999 as shown in figure 4.10.

Table 5: Simpsons Diversity Indices from 1980 to 2016

Year	Diversity	Year	Diversity	Year	Diversity	Year	Diversity
1980	0.490293	1990	0.386548	2000	0.635362	2010	0.658536
1981	0.422915	1991	0.334391	2001	0.620731	2011	0.662041
1982	0.444332	1992	0.322017	2002	0.525673	2012	0.645315
1983	0.546865	1993	0.303632	2003	0.548949	2013	0.637558
1984	0.546584	1994	0.285318	2004	0.635829	2014	0.6851
1985	0.538283	1995	0.378191	2005	0.637062	2015	0.638482
1986	0.46576	1996	0.362707	2006	0.63203	2016	0.640446
1987	0.480122	1997	0.43306	2007	0.622282		
1988	0.382116	1998	0.451402	2008	0.663459		
1989	0.337223	1999	0.573958	2009	0.671149		

This is due to addition of more generation from renewable sources especially geothermal and wind. Low diversity between 1986 and 1998 is attributed to hydropower dominance in generation compared to other sources as presented earlier in figure 4.1. The Simpson's Diversity index is effective because it takes into account the contribution of each member in the system and gives more weight to common or dominant sources. For instance, an energy source that delivers 3 billion kWh is given more weight than one that generates 1 billion kWh. This ensures that sources that are not significantly represented but exist in the energy mix do not significantly affect the diversity. It also explains the annual variation in diversity index despite having fixed energy sources in some instances.

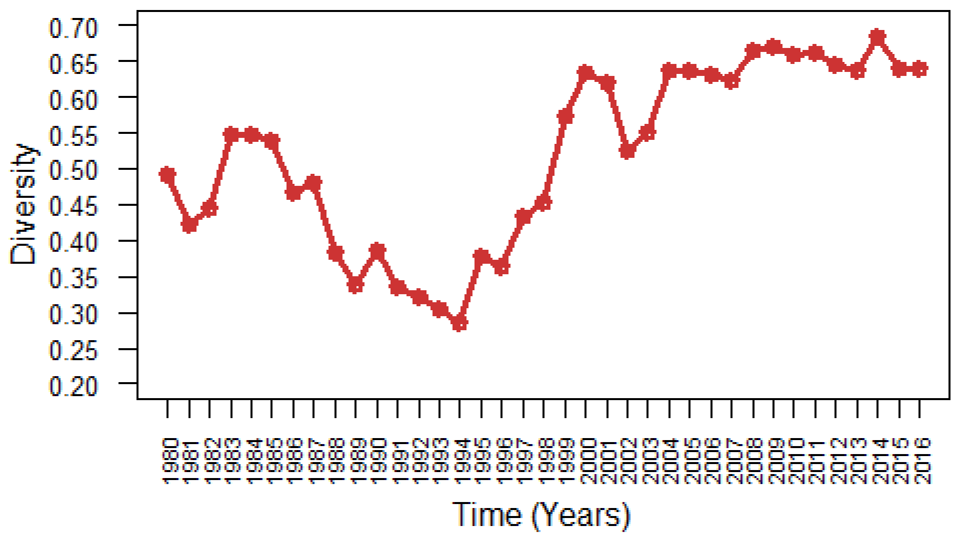

Figure 4.12: Trends in diversity of electricity generation in Kenya

For example, the diversity index has varied between 2010 to 2016 despite having only six sources (hydropower, geothermal, wind, solar, biomass and thermal) over that duration. The variation arises from the variation in the amount of electricity that is generated by each source thus contributing to diversity differently.

The pie charts in figures 4.13 (a) and (b), and 4.14 present the three periods in figure 4.12 that have varied and distinct diversities. All the three periods under consideration have hydropower as the dominant source of electricity. Geothermal, biomass and waste, and thermal generation are present throughout the three periods while solar and wind only surface in the last phase (2005-2016) (figure 4.14). From table 5, the period 1980-1987 has average diversity of 0.6423 compared to 0.6048 and 0.7054 for 1988-1999 and 2005-2016 respectively.

It is noted that the period with the least diversity has a big disparity between the dominant source and the others. In that period, Hydropower accounted for 76.17% of total generation leaving only about 24% to be shared among biomass, thermal and geothermal.

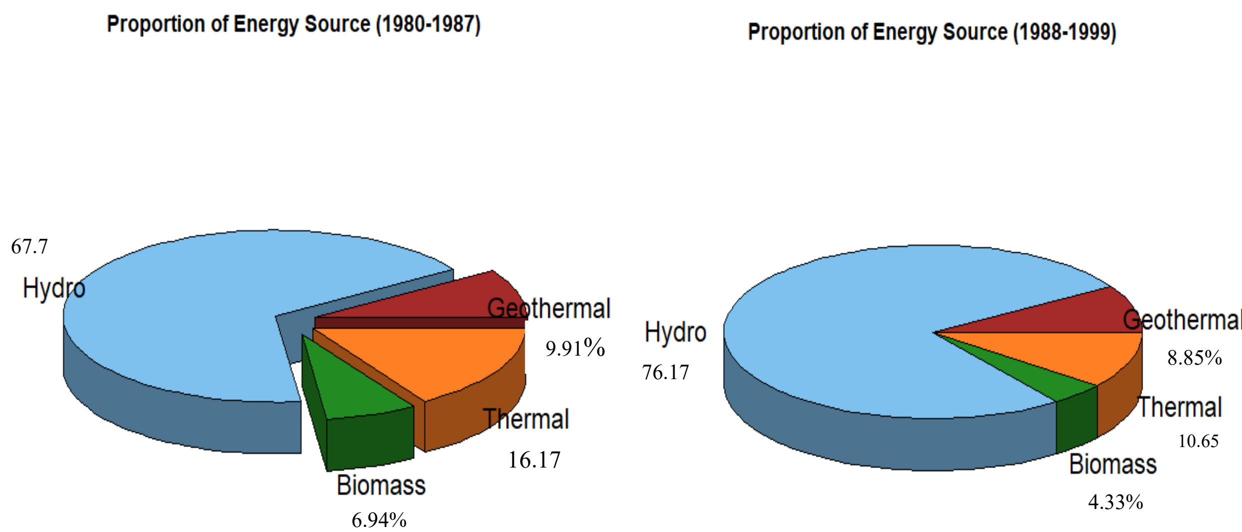

Figure 4.13: Proportion of electricity generation by source for the period 1980-1987 (a) and 1988-1999 (b)

Even though the first two periods have similar number of electricity sources, their diversities are different owing to the distribution in the proportions of these sources. The latter period 2005-2016 has the highest diversity due to the even distribution in the proportions of the electricity generation. This period is more diverse because of addition in generation capacities of geothermal and thermal to reduce domination by hydropower. This period also marked addition of solar and wind in the generation mix.

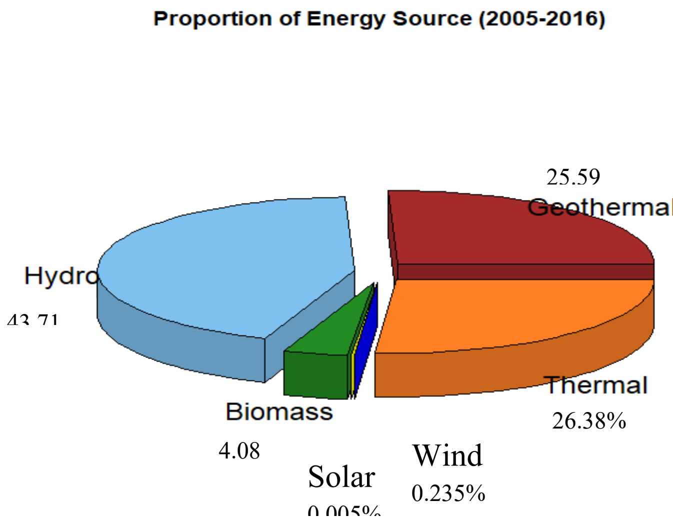

Figure 4.14: Proportion of electricity generation by source for the period 2005-2016

Solar and wind electricity generation may not have significantly influenced the high diversity in this period due to their insignificantly lower proportions. However, stepping up these sources could further increase diversity. It is encouraging that Kenya has a 310MW wind power station located in the Northern part of Kenya in the County Turkana. Despite this being in place, the LTWP at the time of conducting this research did not show any evidence of contributing to the grid as a result of lack of transmission lines.

4.3.2 Spare Capacity

Spare capacity is calculated as the difference between the actual amount of electricity generated in a year and the amount of electricity that could be generated if the power plants were to operate at full capacity. The installed capacity of an electric power plant is the maximum output the plant can generate under ideal conditions. However, electric power plants will always operate below their installed capacity due to a number of factors that affect their performance. Hence the need to include capacity factor of electricity source in the quantification of maximum electricity that can be generated by the source.

The capacity factor is therefore expressed as a ratio of the net electricity generation over a period of time to the amount of electricity that would have been produced at full capacity. Net generation is defined as the gross electricity generation minus the parasitic station load (Mines et al., 2015). Station load is the electricity that is used to operate the electrical power plant while gross generation is the total electricity produced by the generating units as measured at the generating terminal.

Figures 4.15 shows variation in the capacity factors of geothermal, hydropower, thermal and wind energy sources. In the first years, geothermal has relatively low capacity factors, below 35% from 1980 to 1983 and going as low as 14% in 1981. This is due to low electricity generation from geothermal in those years as majority of the electricity was generated from hydropower. However, the capacity factor is observed to rise rapidly to reach a maximum of 88% in the year 1987 and thereafter oscillate between 88% and 60% averaging about 72.28% for the period under consideration. This is in agreement with the typical capacity factor of geothermal whose world average is considered to be about 73.9% by the United States Energy Information Administration (EIA).

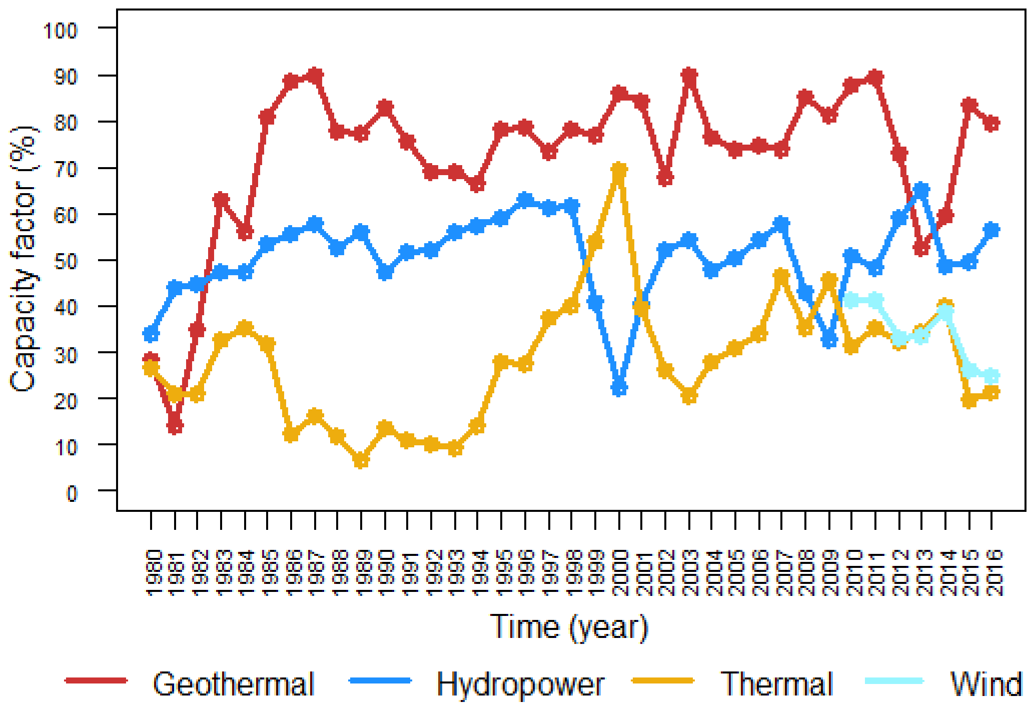

Figure 4.15: Capacity factors of selected electricity sources

Thermal sources portray an irregular pattern in their capacity factor. As discussed earlier, thermal sources in Kenya are used as contingency measure in case of low generation from hydropower and geothermal sources to take care of the deficit in electricity supply. Thus their operation is not steady as they are off and on thus affecting their total output hence a lower average capacity factor of 28.36% for the period under consideration. This is despite the fact that conventional energy sources are known to have higher capacity factors. The data for wind energy is only available from the year 2010. The data available indicate an average capacity factor of 34.06%.

There is a sharp decrease in the wind power capacity factor from 2014 to 2016. This may have resulted from the increase in installed capacity of wind power stations with no net increase in generation. Hydropower capacity factor ranges between 22% to 65% between the years 1980 and 2016. The lowest capacity factor of 22% occurs in the year 2000 when there was least generation from hydropower. The average capacity factor for hydropower was found to be 50.74 which is slightly above the global average of 38.2% (EIA, 2016). This is as a result of the dominance of hydropower in the Kenya's electricity mix. Higher utilization of an energy source could increase the capacity factor of that source because of the high net generation. For instance, Brazil is a country that relies heavily on hydropower for its electricity needs, providing about 77% of total electricity generation. As a result, the capacity power for hydropower in Brazil is 55.98% on average (Fernando et al, 2013).

There are several factors that contribute to the observed fluctuations in the capacity factors of the various energy sources and explain why the capacity factors are lower than 100%. One reason for this observations is that the power plants may be out of service for some part of time because of equipment failure or when undergoing routine maintenance. Power plants may also operate below their capacities due to decrease in demand forcing the power utility to decrease generation. Low electricity prices may also lead to low generation because it may be uneconomical to generate electricity under such conditions.

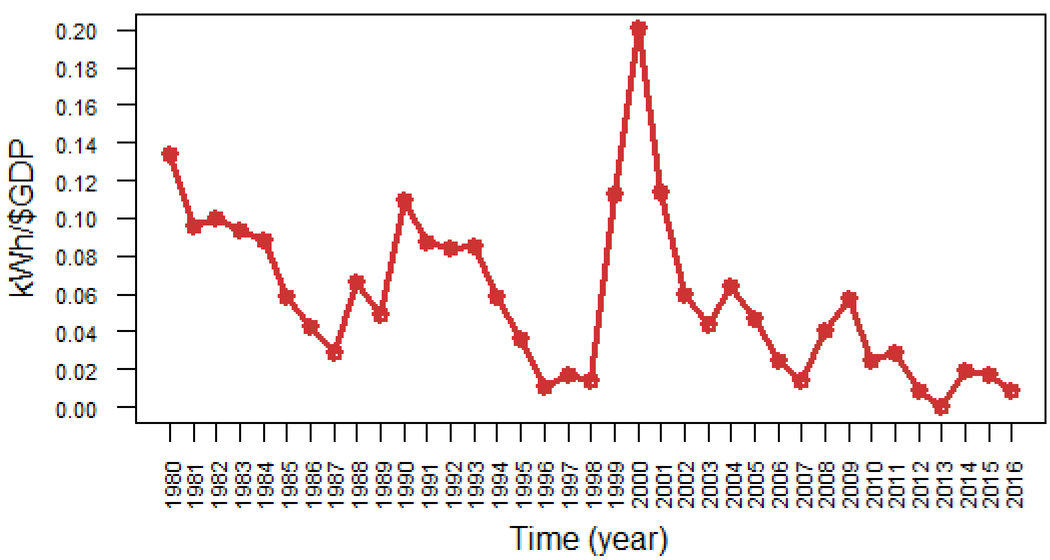

Figure 4.16: Spare capacity from hydropower plants in kWh/$GDP

From the definition of spare capacity, it can be concluded that spare capacity is highest when electricity generation from a certain amount of installed capacity is low and lowest as generation approaches installed capacity. For instance, a power plant with an installed capacity of 100MW and a capacity factor of 80% will have a spare capacity of 0 kWh/$GDP if electricity generated in a certain year were 0.7 billion kWh. For hydropower, there is a decreasing trend in the spare capacity with a peak in the year 2000 (0.2 kWh/$GDP) and the lowest values are associated with the recent years from 2012 to 2016 as shown in figure 4.16. The year with the highest spare capacity (2000) is also the year where electricity generation from hydropower was the least.

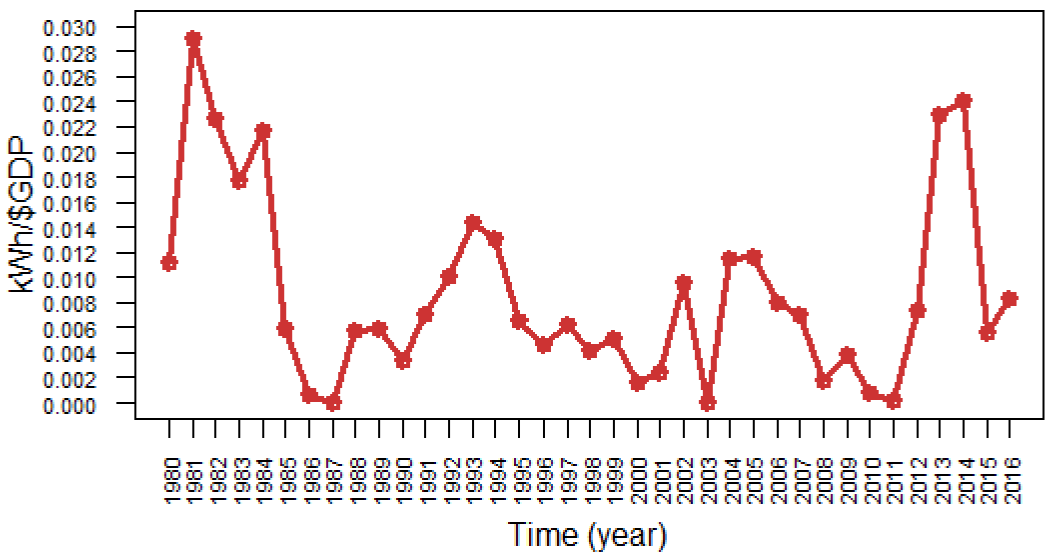

Figure 4.17: Spare capacity from geothermal plants in kWh/$GDP

A decreasing trend in spare capacity signifies increasing generation capacity from installed hydropower capacity. The average spare capacity for hydropower for the period was found to be 0.0579 kWh/$GDP. Spare capacity values from geothermal power (figure 4.17) are relatively lower compared to those of hydropower. Averaging only about 0.0087 kWh/$GDP for the period under consideration, geothermal has the least spare capacity among the three energy sources considered in this section. The least spare capacity can be attributed to its high capacity factor ensuring maximum utilization of the resource thus less is spared. The earlier period (1980 to 1983) is associated with relatively higher spare capacity values which could be as a result of low net generation capacity.

A similar observation can also be made for the years 2013 and 2014 but this may be due to expansion of installed capacity without corresponding increase in net electricity generation. However, the spare capacity is lowered in 2015 and 2016 (figure 4.17) because of stepping up geothermal electricity generation.

Figure 4.18 shows a visual impression of the trends in thermal electricity spare capacity. It is observed that thermal sources have higher spare capacity compared to hydropower and geothermal. At an average spare capacity of about 0.0774 kWh/$GDP, thermal electricity generation in Kenya is highly underutilized. In many occasions, it is usually utilized under emergency cases. Nonetheless, a decreasing trend in its spare capacity is observed as shown in figure 4.18 signifying more venturing into these resources.

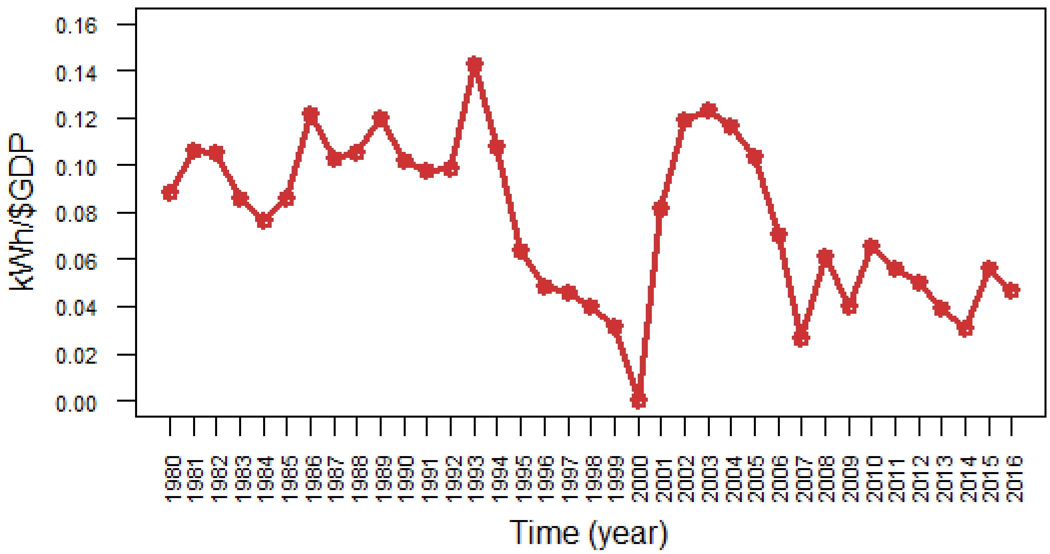

Figure 4.18: Spare capacity from thermal plants in kWh/$GDP

The least spare capacity was in the year 2000 which is the year that saw maximum utilization of thermal resources as a result of low generation from hydropower which was the dominant electricity source then.

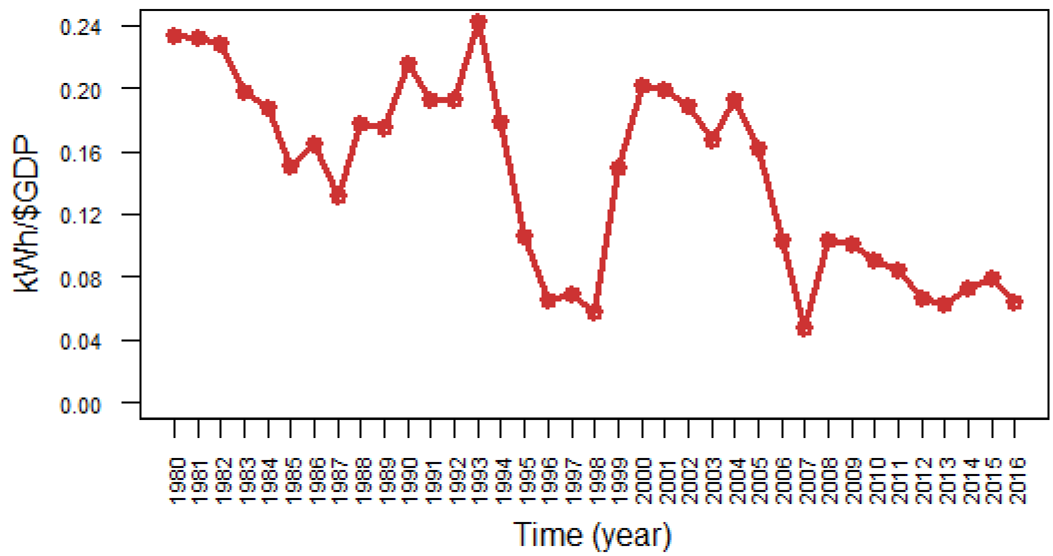

Figure 4.19: Total spare capacity from hydro, geothermal and thermal power plants in kWh/$GDP

Hydropower, Geothermal and thermal electricity sources account for majority of electricity generated in Kenya. When combined together as shown in figure 4.19, they portray a decreasing trend in the spare capacity with an average of 0.144 kWh/$GDP for the period under consideration. The decreasing trend in spare capacity indicate the ever increasing demand for electricity for both domestic and industrial needs. The decrease is also due to the increase in the GDP which was used to standardize spare capacity values. However, while Kenya's GDP continues to ever increase, electricity demand has also been on the rise which has to be accompanied by an increase in generation. Increasing electricity generation calls for expansion of installed capacity to avoid shortages which are usually manifested by frequent blackouts and power rationing. Expanding installed capacity ensures sufficient spare capacity which may be utilized in situations of peak demand.

4.3.3 System Structure

The structure of components flow within a system influences both input and outputs of the system. Therefore, the organizational structure of a system is of utmost importance in the effective operation of the system. In this analysis, system structure is defined by two metrics; the efficiency of electricity generation and importation of electricity. Energy security calls for energy systems to be efficient in their use of resource which can be achieved through regulation and competition that facilitates efficiency.

a) The Imports Metric

Importation of electricity is an aspect of structure that measures the availability of generation. In cases where generation is not available or is not adequate to respond to demand, importation of electricity from neighbouring countries serves to fill the deficit. Coupled with the use of imported diesel for electricity generation, electricity imports have an implication to the performance of the system and portrays inadequateness within the system. This metric will also take care of surplus generation that is usually exported by use of the Net Export/Import (NEI) indicator. The Net Exports of electricity is given as the difference between electricity exported and electricity imported and it may be either negative or positive. A country with negative net exports buys more than it exports and this has implication to the underlying structure. This metric therefore comprises both importation and exportation of electricity.

Historically, Kenya has been importing electricity from Uganda since the year 1957 under an agreement made in the colonial era which was later renegotiated in 1997. Kenya also used to import electricity from Ethiopia which was only utilised in the border town of Moyale but the country later stepped up plans to have the imported power connected to the national grid. Kenya Power purchases electricity from Tanzania Electricity Supply Company Limited (TANESCO), Uganda Electricity Transmission Company Limited (UETCL) and the Ethiopian Electric Power Corporation (EEPCO).

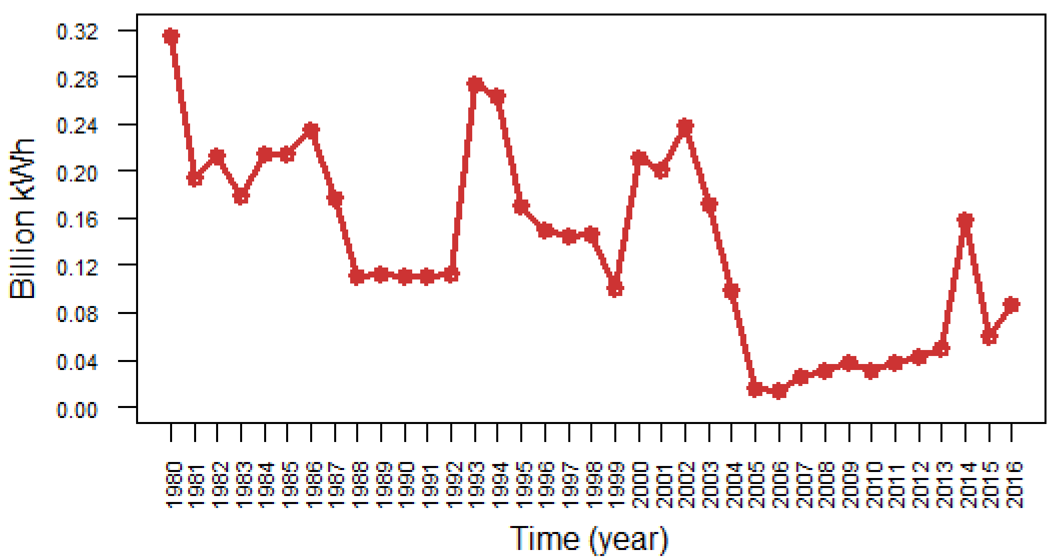

Figure 4.20: Total electricity import in billion kWh

Electricity importation has been on a steady decline reaching the lowest value in 2015 thereafter followed by a steady increase (figure 4.20). The decline in electricity imports is as a result of increasing local generation capacity while increase in imports signifies increasing local demand and poor hydrologic conditions. The drought that was experienced in Kenya in 2014 had devastating effects on hydropower resources leading to a sharp rise in electricity imports from 0.05 billion kWh in 2013 to 0.16 billion kWh in 2014 as shown in figure 4.20. The electricity sector in Kenya seemed to rely a lot on hydropower that electricity imports are low during wet years when there was enhanced generation from hydro sources.

For instance, the year 1997 remains one of the most wet years in Kenya and is also associated with low electricity imports. However, the sharp fall in electricity imports 2002 and 2005 is not explained by weather conditions since the years 2002, 2003 and 2004 were much wetter than 2005. This decline can be explained by a rise in geothermal and thermal generation during the same period as presented earlier in figure 4.1. This sharp decrease also coincided with the period which Kenya recorded significant exports in electricity while drawing back on electricity imports.

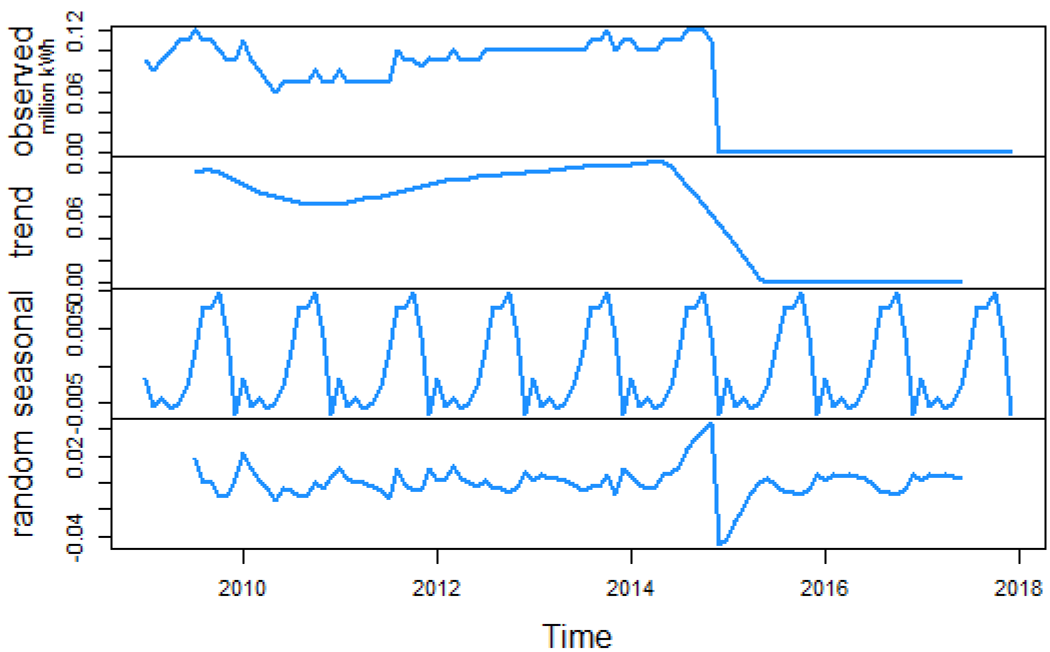

Figure 4.21: Electricity imports from Tanzania time series decomposition

Figure 4.21 shows that Kenya used to import electricity from Tanzania until November 2014 when electricity importation from Dar es Salaam to Nairobi through Lunga Lunga was stopped. Most of electricity imported from Tanzania was during the July-November season.

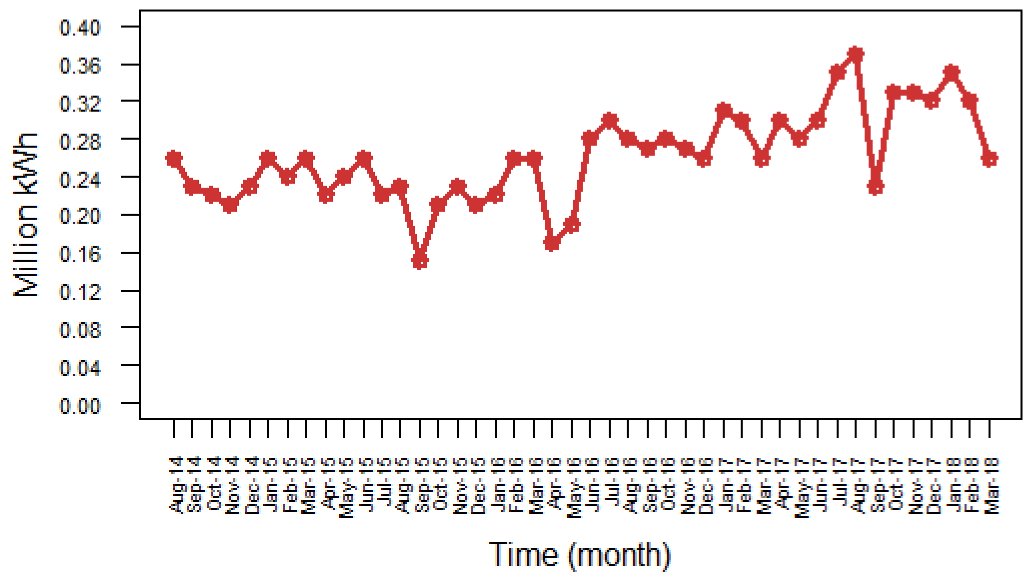

Figure 4.22: Monthly electricity imports from Ethiopia

Kenya has recently started importing electricity from Ethiopia and this has increased over time as shown in figure 4.22. The plan to import electricity from Ethiopia was to help solve chronic power outages and reduce reliance on thermal power that has been fuelling consumer prices.

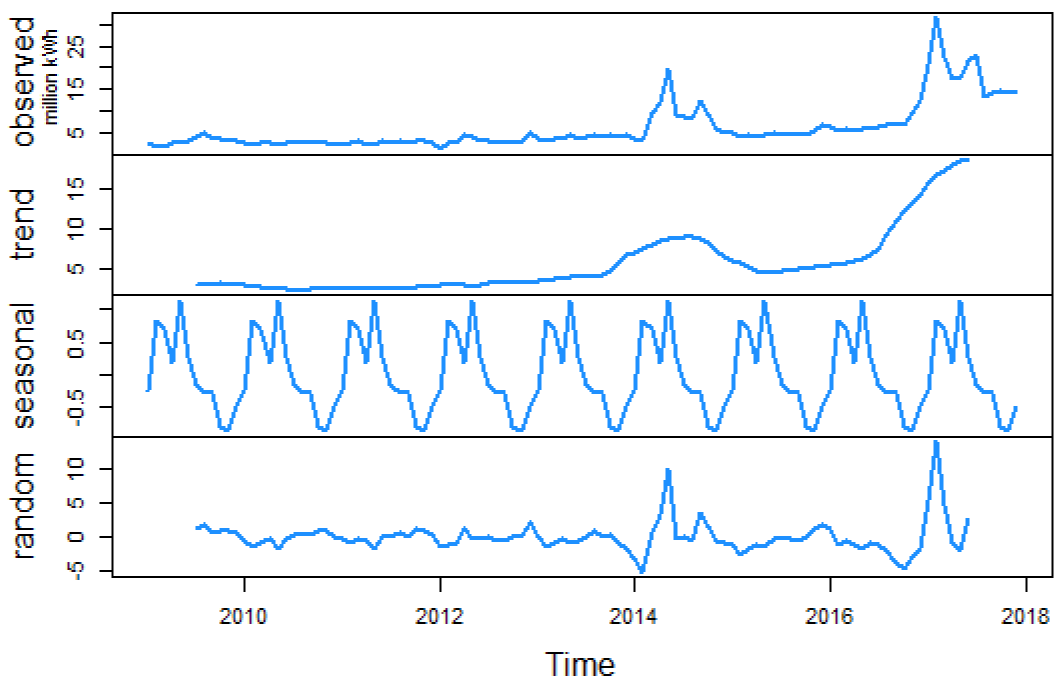

Figure 4.23: Monthly electricity imports from Uganda

Kenya imports huge amount of electricity from Uganda compared to Tanzania and Ethiopia. Imports from Uganda rose significantly in 2014 due to the drought that was experienced in the country, similar with 2017 (figure 4.23). Unlike import from Ethiopia, electricity imported from Uganda only serves western Kenya and is therefore not fed to the national grid. From the bi-modal seasonal pattern in figure 4.23, most electricity from Uganda is imported during the months of February to June.

Currently Kenya imports power from the named countries when demand exceeds supply and also exports electricity to Tanzania, Uganda and now Rwanda when there is surplus. However, as a result of increased electricity generation from geothermal, Kenya stepped up electricity export in 2004 as shown in figure 4.24 (a). Kenya is a member of the East African Power Pool (EAPP) and member countries are required to sell surplus electricity subject to availability. The EAPP was formed in 2005 with Uganda, Kenya, Burundi, Democratic Republic of Congo (DRC), Egypt, Ethiopia, Rwanda and Sudan as member countries.

Tanzania later joined in 2010. Having seen increase in local generation mainly due to geothermal power, Kenya became self-sufficiency in electricity and cut its electricity imports thus allowing export. In 2006, total electricity exports reached a high at 73 million kWh (figure 4.24 a). However, export depends on availability of surplus and is therefore not steady because of fluctuations in supply and demand.

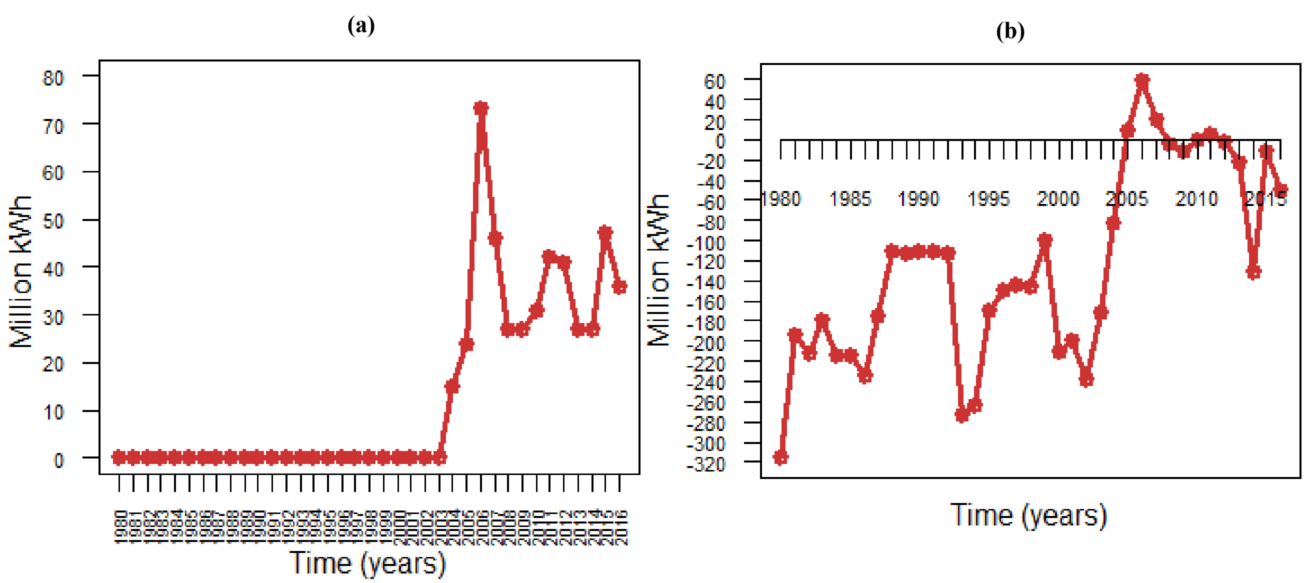

Figure 4.24: Total electricity exports (a) and Net flow of electricity across Kenyan borders (b)

Despite recently stepping up generation and having seen electricity exports improve, Kenya has remained to be a net electricity importer for long. Only the years 2005, 2006, 2007 and 2011 have recorded more electricity exported than imported as shown by the net flow of electricity in figure 4.24 (b). In 2010, the country had 0 net imports having recorded similar amounts of exports and imports at 31 million kWh.

The imports metric indices comprise the net imports that are weighted by total electricity consumed and the net exports which are weighted against total electricity generated locally. For purposes of this analysis, electricity coming to the system is denoted as positive while electricity being channelled out the system is denoted as negative. The import metric is therefore positive for most of the duration considered while only the years 2005, 2006, 2007 and 2011 have infinitely small positive values as shown in figure 4.25.

The second part of equation 5 becomes null for most years as a result of the net exports component being negative thus rendering the net export indicator (θ) zero. Note that it is not practically possible to have both net imports and net exports components of equation 8 contributing to the import metric index. Also, the import metric indices act analogous to the net flow of electricity across Kenyan borders (figure 4.24b) but diametrically opposed.

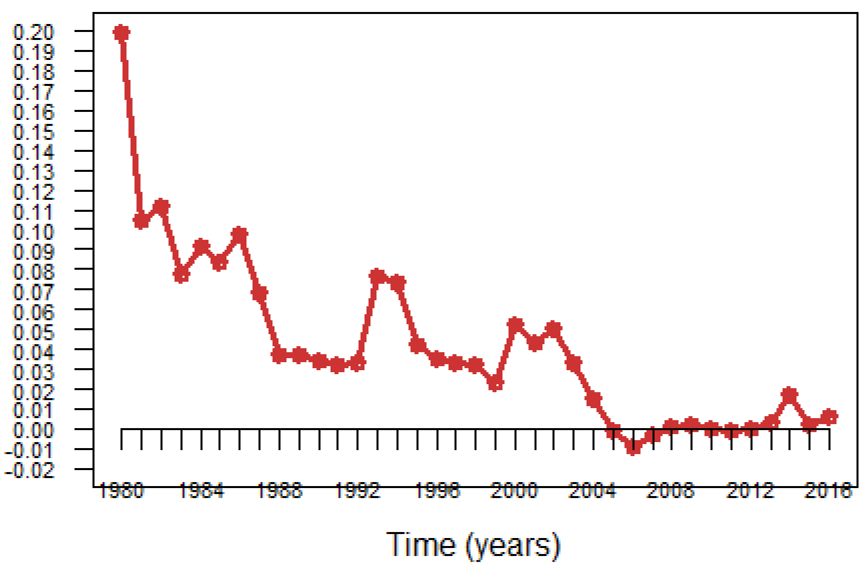

Figure 4.25: Import metric indices (1980 to 2016)

b) Efficiency metric

Energy efficiency has been an important political agenda as energy regulators device ways to reduce wasteful in energy consumption and formulate policies that strengthen energy security. In many economic analyses, energy intensity is always taken to be a measure of energy efficiency for a country (IEA, 2014). It should be noted that lack of sufficient data on energy efficiency has been an impending factor in the quantification of energy efficiency. The parameters for measuring energy intensity are easily available thus making many analysists to resort to energy intensity as a proxy for energy efficiency. Energy intensity is taken to be a measure of energy efficiency and is expressed as the ratio of the total primary energy supply to the gross domestic product of a country.

The assertion drawn from the foregoing is that low energy intensity signifies high efficiency and high energy intensity signifies low energy efficiency. However, low energy intensity of a country may be as a result of size and industrial activity of a country and may not in any way represent efficiency in energy structures of the country. Efficiency may contribute to energy intensity, however, several other factors need to be considered such as structure of the energy system. In this regard, this analysis will consider the transmission and distribution losses in the electric grid. System losses comprise both technical and commercial losses where technical losses are as a result of the inherent nature of the system.

Commercial losses comprise losses that are incurred due to erroneous metering or theft. Transmission and distribution losses in this analysis refer to technical losses that occur due to physical properties of electricity transmission system, mainly resistance. The losses comprise energy that is lost in transformers, conductors and within the transmission line. These losses are affected by a number of factors including the length of distribution line, size of conductors of the distribution line, overloading of transmission lines and distance of distribution transformers away from load centres. Figure 4.26 illustrates historical trends in transmission and distribution losses in the national electricity grid.

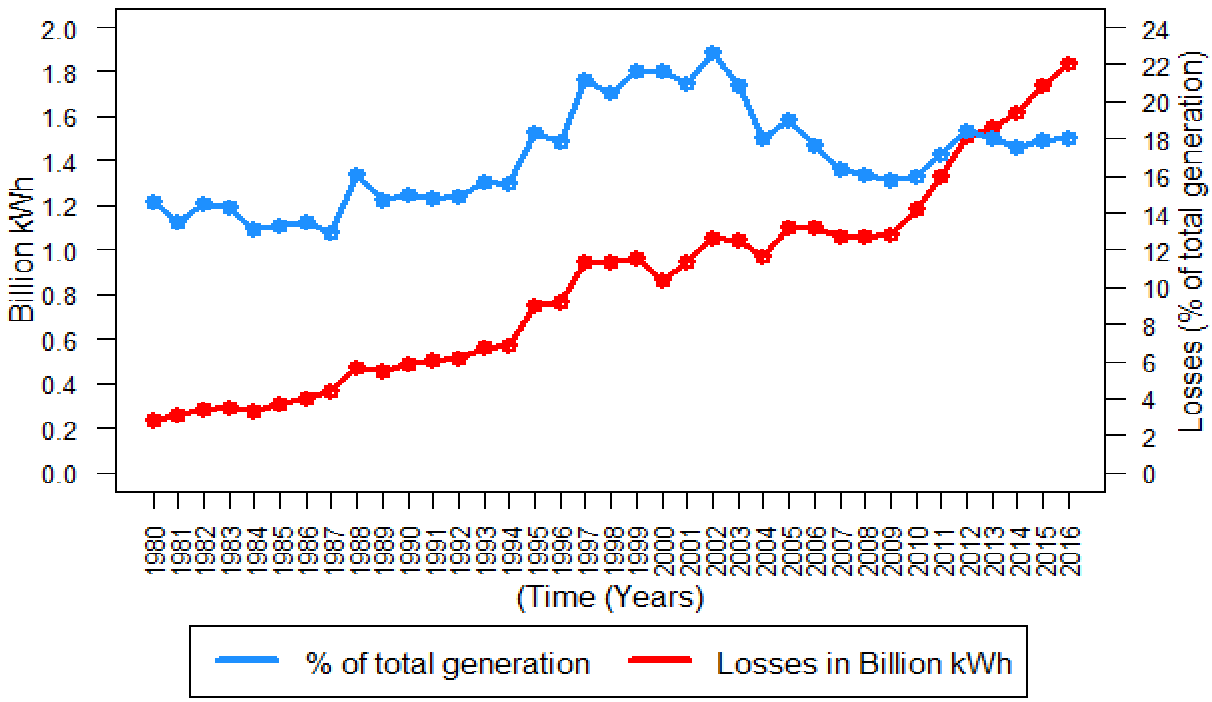

Figure 4.26: Electric power transmission and distribution losses

It is observed that transmission losses have been increasing since the year 1980 to reach a maximum in the year 2016 (1.8 billion kWh) as shown in figure 4.26. The data portrays an increasing trend implying that transmission losses have been increasing with increase in the amount of electricity generated. The increase in losses can be attributed to the commissioning of new plants without corresponding increase in transmission capacity. There has also been increase in the connection of new electricity customers by double digits over some periods as a result of the Rural Electrification Program (REA). The REA came in place under the Energy Act of 2006 which became operational 2007.

For instance, there were 735,144 customers connected to the national grid in the year 2004. This figure rose to 2,060,449 customers in 2012 leading to increase in voltage losses due to grid extension. Majority of these customers are connected to the low voltage network. Transmission and distribution lines circuit length was 37,149km in 2007 increasing by about 10km to 47,035km in 2012 (KPLC, 2013). These lengths include 220, 132, 66, 40, 33, and 11 kilo Volts (kV) lines. Another factor that could have contributed to the increase in transmission and distribution losses is installation of a large number of distribution transformers which have rose from 1,596 in 2007 to 1,846 in 2012 according to data by the Kenya Power Company. The percentage loss is calculated as a percentage of the total electricity generated.

This loss is observed to be low (less than 14.5%) in the earlier years, rising to a maximum of 22.5% in 2002 then dropping again to reach 16% in 2009.

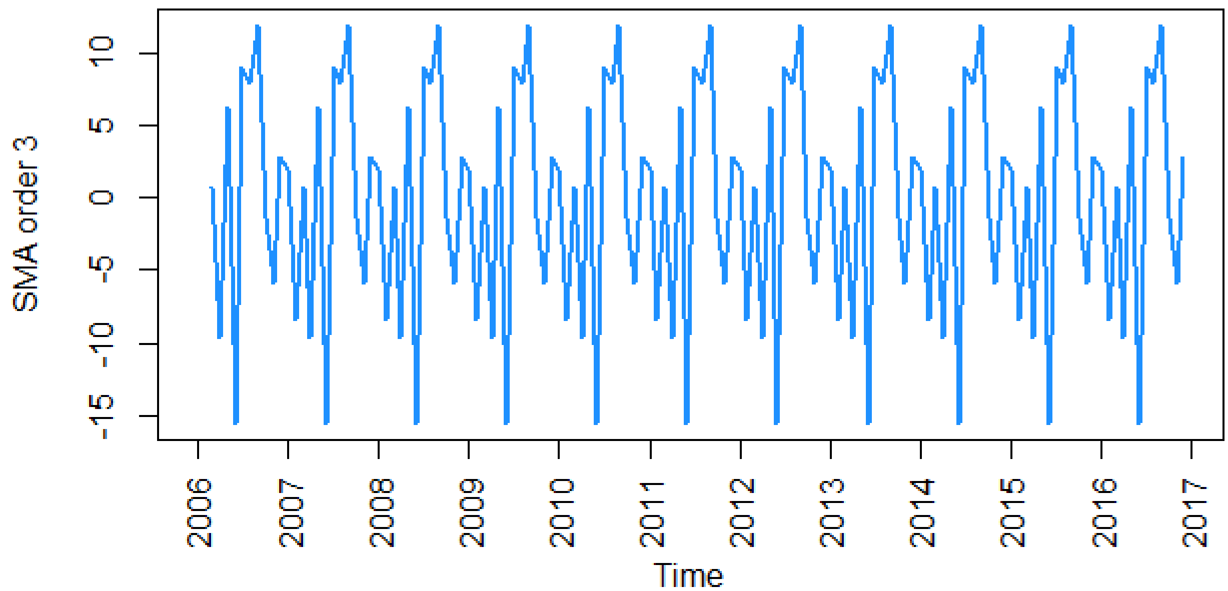

Figure 4.27: Simple moving average of order 3 of the seasonal component of transmission and distribution losses

The transmission losses in 2016 may be only 18% of total electricity generated corresponding to about 1.8 billion kWh. However, in practise, this figure is quite significant that it can service 720,000 urban middle income households with annual electricity consumption of 2500kWh for a whole year. A simple moving average (SMA) of order 3 shows the seasonal distribution of transmission losses as presented in figure 4.27. Transmission and distribution losses exhibit a tri-modal seasonal pattern with peaks in December-January, May and July-September. A minor peak is also present in March though insignificant compared to the three distinct peaks. The troughs occur during the months of February, April, June and October-November. This pattern follows electricity generation pattern with months associated with more electricity generation experiencing peaks in transmission and distribution losses while those with the least generation are associated with troughs.

Due to transmission and distribution losses and other factors, not all the electricity generated is sold to consumers by the Kenya Power Company. Figure 4.28 shows the distribution of proportion of electricity units sold. About 76-81% of the electricity generated in Kenya in sold by Kenya Power Company. The rest (19-24%) is lost as technical and commercial losses. Averagely, technical losses are about 19% of total generation (figure 4.26).

This implies that about 5% of the electricity generated is lost as commercial losses which may include erroneous meter readings and illegal connection.

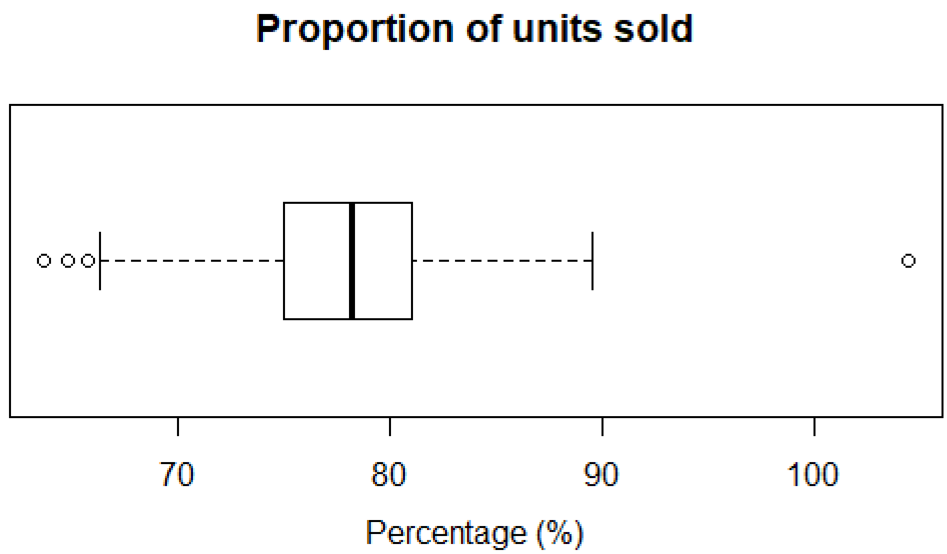

Figure 4.28: Box plot of electricity units sold as a percentage of total electricity generation

Illegal electricity connections may prove to be an obstacle in quantifying the extend of losses within the transmission lines as it is not always straightforward to determine the proportion of electricity lost through theft.

4.4 Dependent Variable: Electricity Price

The most effective way for an energy system to respond to both internal and external disturbances is through price. Drastic changes in price especially sharp increases may signify supply constraints. Increases in price will reduce demand and in this way allow adjustments within the system in attempt to deal with the disruption. Electricity price is therefore included in this analysis as a dependent variable which reflects the ability of the electricity structure to respond to change. Electricity price in Kenya is regulated by the Energy Regulatory Commission (ERC). Established under the Energy Act 2006, the ERC has mandate to set, review and adjust electric power tariffs and investigate tariff charges. New electricity tariffs are set and announced on the 6th day of each month. As a result of different sources of generation that have been discussed earlier, electricity tariffs have several components. Kenya Power proposes to the ERC a fixed charge that is to be levied per kWh of electricity consumed by consumers. This is then effected after approval by the ERC. This levy does not change regularly and the last time Kenya Power reviewed this levy was in 2015 which was still in use as of April 2018.

Other charges that are set and levied to electricity consumers are Fuel Cost Charge (FCC), Foreign Exchange Rate Fluctuation Adjustment (FERFA), Inflation Adjustment (IA), Water Resource Management Authority (WARMA) levy, ERC levy, Rural Electrification Program (REP) levy, and Value Added Tax (VAT).

The FCC is charged per kWh and it reflects the cost of generating electricity from thermal power plants. IA levy is set every six months and is affected by the consumer price index (CPI) and the CPI for urban consumers published by United States Department of Labour Statistics. FERFA represents foreign currency costs incurred by KenGen and KPLC and are not related to production of electricity. WARMA levy is charged based on the amount of electricity supplied by hydropower. ERC levy is fixed at $0.03 cents per kWh to cover its operational costs while REP is allocated 5% of the base rate. A VAT of 16% is charged on every other component except WARMA, ERC and REP levies. All these components added together form the monthly electricity price per kWh charged by Kenya Power. FCC is the most variable component and has great influence on the price of electricity given the high volatility of oil prices for country that imports oil for electricity generation.

Electricity tariffs are also determined by sector and each sector has its unique price. These sectors are; Domestic Consumption (DC), Small Commercial (SC), Commercial (CI1), Commercial (CI2), Commercial (CI3), Commercial (CI4), Commercial (CI5) and Domestic Water heating (IT). DC comprise a category of consumers on 240V. In this category, a fixed amount of KES150 is charged per month while the first 50kWh consumed are charged at a rate of KES2.50, 50 to 1500kWh attracts KES12.75 per kWh and above 1500kWh is billed at KES20.57 as shown in table 6. Most electricity consumers fall in this category and there is no demand charge for this category. The commercial sectors have peak and off peak rates where off peak rates are about half peak rates. The off peak rates are lower so that industries can be encouraged to take advantage of the reduced tariffs by operating night shifts when demand is low. Off peak rates are normally applied from 10 pm when there is reduced load but electricity generation remains unchanged thus implying losses for the supply utility.

Despite having majority of the consumers in the DC and SC categories, the large and medium commercial categories account for the largest share of electricity consumed as shown in figure 4.29. In the years 2004, 2005 and 2006 domestic and small consumers consumed nearly half the amount consumed by large and medium commercial consumers. However, DC and SC have increased rapidly in the recent years reducing the gap with large and medium commercial consumers. This increase can be attributed to recent government's efforts to increase the number of Kenyans with access to electricity and also the REP.

Table 6: Electricity tariffs per sector

Tariff	Fixed charge (KES)	Energy charge (KES per kWh)	Demand charge (KES per kVA)
DC (Domestic, 240 V)	150	First 50kWh:2.50 50 to 1 500kWh:12.75 Thereafter:20.57	NILL
SC (Small Commercial, 240 V)	150	13.5	NILL
CI1 (Commercial, 415 V)	2 500	Peak: 9.20 Off peak: 4.60	800
CI2 (Commercial, 11 kV)	4 500	Peak: 8.00 Off peak: 4.00	520
CI3 (Commercial, 33 kV)	5 500	Peak: 7.50 Off peak: 3.75	270
CI4 (Commercial, 66 kV)	6 500	Peak: 7.30 Off peak: 3.65	220
CI5 (Commercial, 132 kV)	17 000	Peak: 7.10 Off peak: 3.55	220
IT (Domestic water heating)	150	13.5	NILL

Electricity consumers have two billing plans to choose from. The Post pay plan is where a consumer uses power and then billed afterwards, usually at the end of every month. The other option is the pre pay option where consumers purchase electricity units for use.

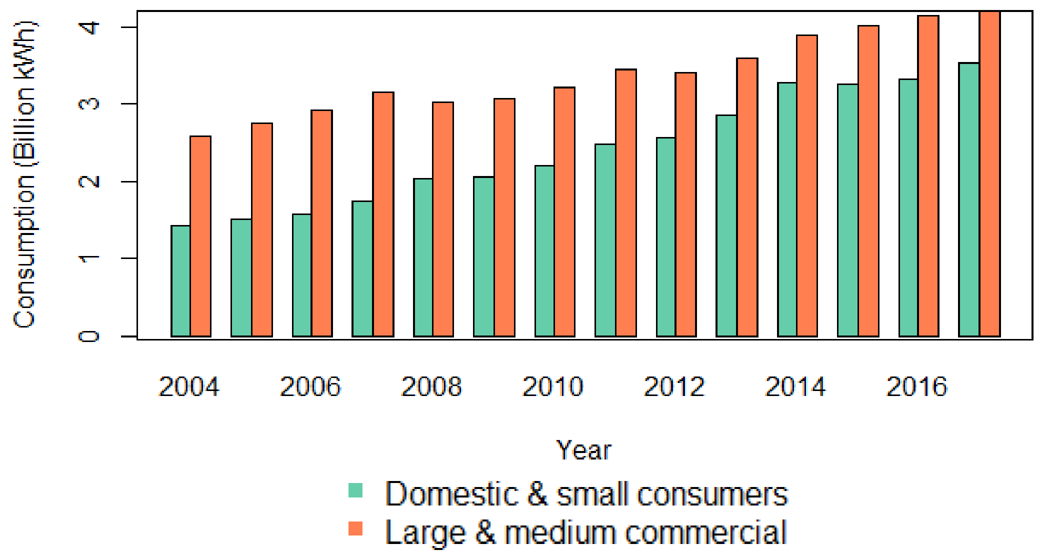

Figure 4.29: DC, SC and large and medium commercial consumers

Most domestic consumers in Kenya have installed pre pay meters. This billing method is preferred by domestic consumers because it is convenient and flexible, allowing purchase of electricity units at any given time via mobile banking system.

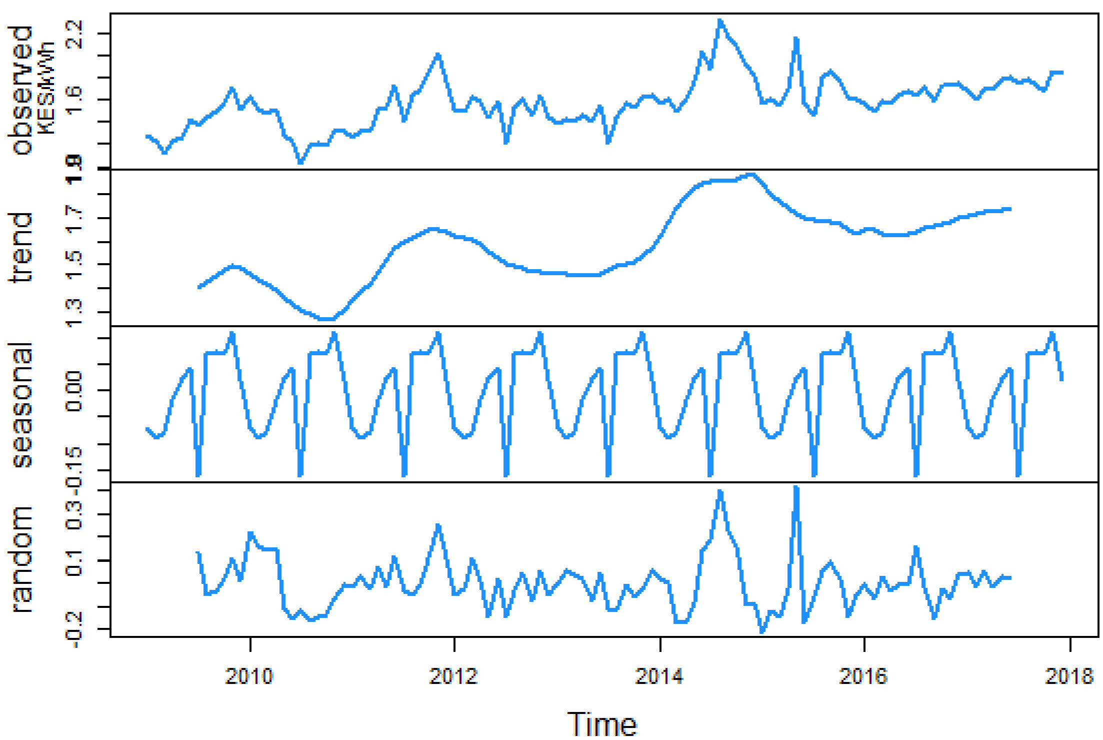

Figure 4.30: Decomposition of the weighted prices of electricity (Jan 2009 to Dec 2017)

The actual electricity prices are weighted against the Kilowatt-hours of electricity sold by the Kenya Power Company. This gives more weight to prices corresponding to the highest electricity sales than those that correspond to low electricity sales. Figure 4.30 shows the observed, trend, seasonal and random components of the monthly weighted average prices of electricity. The general indication is a non-linear increasing trend in electricity prices with more randomness.

In 2014, drought conditions leading to depressed hydropower generation might have contributed to the high electricity prices in that year. This may be as a result of increased thermal generation to fill the deficit in hydropower. The weighted prices exhibit a bi-modal seasonal pattern with two distinct peaks occurring in May-June and August-December implying higher electricity prices during these months. The period February to June is when Kenya imports most electricity especially from Uganda and the high prices during this season may be due to electricity deficiency in the country. The lowest electricity prices occur between January and April and during the month of July which are associated with troughs in the seasonal component of figure 4.30. Figure 4.31 shows decomposition of the FCC component charged on electricity consumers.

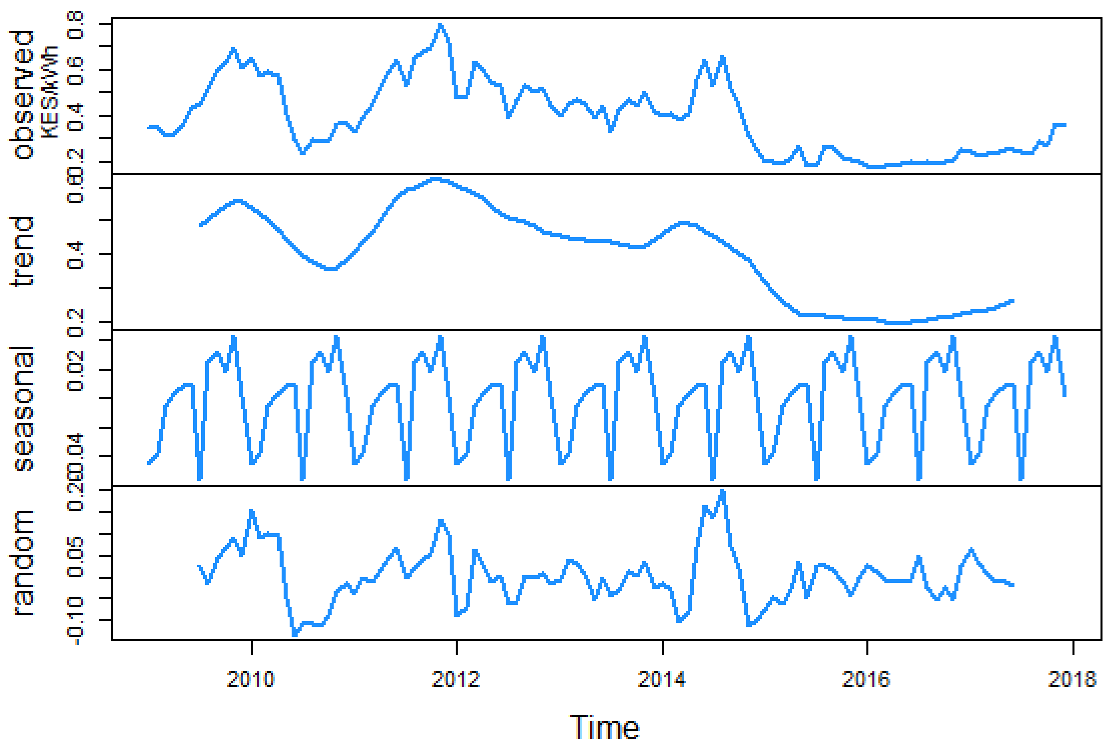

Figure 4.31: Decomposition of the weighted average prices of the Fuel Cost Charge (FCC) Component (Jan 2009 to Dec 2017)

It is worth noting that the FCC component is not only dependent on the amount of electricity supplied from thermal generation but also the global oil price. The lowest FCC prices were recorded between January 2016 and November 2016 while December 2011 recorded the highest FCC charge. The general trend in FCC prices is decreasing over the period January 2009 to December 2017. The high FCC charges between 2009 and 2014 were as a result of high oil prices in the global oil market while the decline in FCC charges from 2015 was due to decrease in global oil prices as discussed in the section 4.5. Similar with the weighted total electricity prices, the weighted FCC price also shows high randomness as shown by the random component in figure 4.31 and in many instances it lacks a general trend. The seasonal component also follows a similar pattern as that of the total electricity price. Recent increase in electricity prices between February 2016 and December 2017 (figure 4.30) correspond to an increase in FCC charge over the same period. Thermal generation is expensive compared to renewable sources and is highly susceptible to changes in oil prices. However, despite increasing generation and reduction in electricity imports, electricity prices have continued to increase in recent times implying that factors other than electricity shortage might be affecting electricity prices. A large share of electricity sold is consumed by large industrial consumers.

4.5 Resilience metrics vs Electricity Generation

The amount of electricity generated is determined by a number of factors, some of those factors have been discussed before in this analysis. The factors discussed so far comprise the three resilience metrics; diversity, spare capacity and the import metric. Figure 4.32 shows a summary of correlation among the resilience metrics and generation. Positive correlations are displayed in blue while red stands for negative correlations. Colour intensity and the size of the circle are proportional to the correlation coefficients. Diversity represents alternative electricity options that are actually utilized. More generation options imply more generation capacity. Correlation coefficient between diversity and electricity generation is 0.64 representing a positive relationship. Importation of electricity is usually as a result of insufficient in generation.

A negative relationship therefore exists between the imports metric and electricity generation with a correlation coefficient of -0.79. Increase in electricity imports signify inability of the energy system to satisfy demand needs through local generation. Spare capacity is the differences between installed electricity capacity and the actual electricity generated and standardized using the Real Gross Domestic Product. Increase in generation will lower the spare capacity unless installed capacity is increased by the same amount. However, it is not common that installed capacity will always be increased in synchrony with generation capacity. Most times, generation fluctuates without corresponding changes in the installed capacity. Correlation between generation and spare capacity is therefore negative (-0.74) signifying inverse relation. All the correlation coefficients were significant. Import metric and spare capacity are highly correlated because increase in spare capacity signifies decreased generation hence need for more imports to fill the deficit.

Figure 4.32: Correlation matrix of resilience metrics and electricity generation

4.6 Oil Price Shocks Episodes

Oil price shocks are the unexpected changes in price of oil that are mainly propagated by uncertainty surrounding the future availability of crude oil, market imbalances (demand shocks) and geopolitical events such as civil wars within OPEC countries (Economou, 2016). Oil price shocks are mainly felt by countries that import oil or oil products one way governments deal with these events is by imposing the price on consumers.

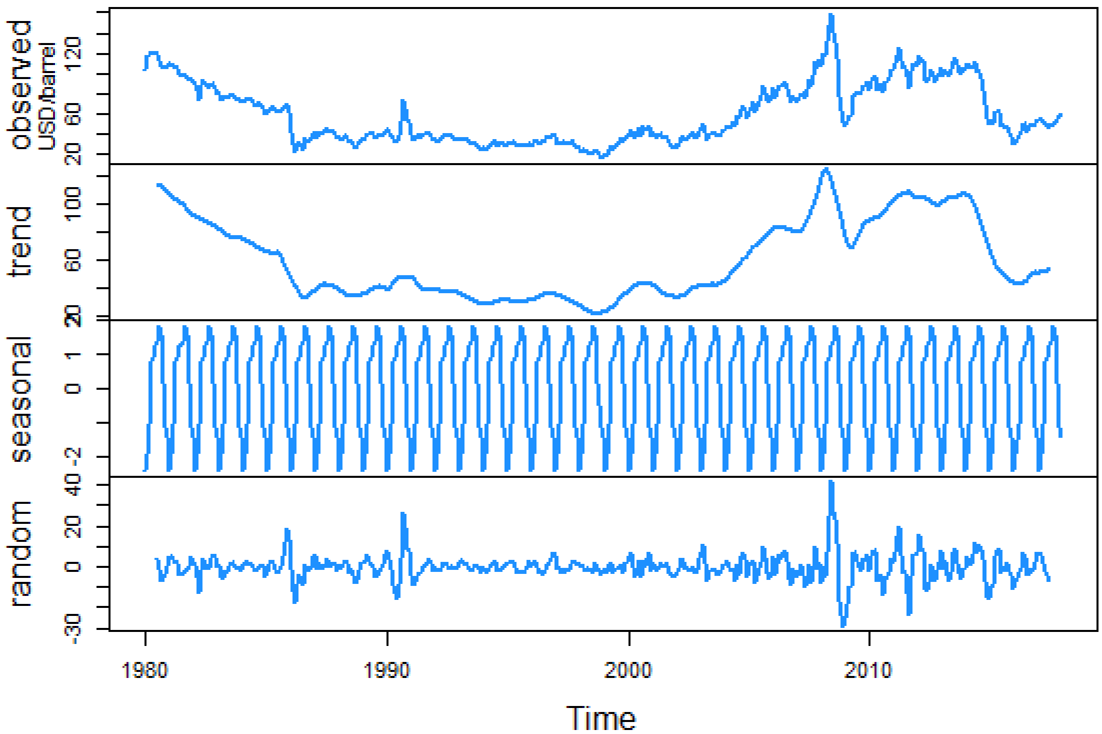

Figure 4.33: Historical monthly oil prices from Jan 1980 to December 2017

Oil price shock is represented by the difference between the expected price of oil and the actual price that occurred (Baumeister & Killian, 2016). For countries that rely on thermal electricity generation using diesel, there can be devastating effects to the electricity system in such events. Figure 4.33 shows crude oil prices per barrel in US dollars. From the figure, it is evident that oil prices do not follow any specific trend, making it difficult to predict. The real datasets for oil prices were adjusted for inflation using the headline consumer price index (CPI) with the current month as the base. Throughout this period (Jan 1980 to March 2018), there has been sharp oil price increases occurring at irregular intervals. Since the 1980s, several authors have documented literature in an attempt to explain the causes of oil price fluctuations. These fluctuations reflect disruptions in production of oil globally and are caused by external political wars in oil producing countries especially those in the Middle East (Barsky and Killian, 2004).

Some of the notable events leading to increase in oil prices include the Iranian Revolution that started in October 1978 leading to increase in oil price in early 1980. This increase in oil price may have been caused by the reduction in the oil production in Iran according to views held by (Hamilton, 2012). High oil prices witnessed in 1980 may also be as a result of the outbreak of Iran-Iraq war in September 1980. The 1980 oil crisis that triggered the price shocks for that year saw oil prices rise to $121 in April 2018 from as low as $55 in April the previous year. The invasion of Kuwait in August 1990 coincided with high oil prices in that year.

Shifts in demand (positive demand shock) for oil acts to raise the price of oil and also increases global oil production for that month (Kilian and Murphy, 2014). This is a more modern and objective approach to assessing causes of oil prices than the approach by Hamilton which may be viewed as a traditional approach. The wars and revolutions witnessed in the middle may have had an effect on the expectations of oil prices but it is important to note that modern empirical oil market models that take into account both demand and supply shocks have confirmed demand shocks as having played a major role in the 1980 oil price increase. The price of oil reached all time low in December 1998 and this could be associated with reduced demand for crude oil. This drop was followed by a period of increasing oil prices that was marked by a remarkable increase in oil prices between 2003 and 2008 to level even higher than those witnessed in the early 1980s. Views held by (Killian, 2008b) and (Hamilton, 2012) suggest that this increase in oil prices was as a result of increase in oil demand over several years due to the expansion of the global economy.

The oil price shock of 2008 saw oil prices reach a high of $159 in June 2008 but the surge in oil prices only lasted up to September that year and thereafter followed by a sharp recession from October the same year. This recession is attributed to financial crisis witnessed in late 2008 thus dealing a blow to demand of crude oil (Baumeister and Kilian, 2016a). Other demand and supply shocks can be seen between 2010 and 2014 leading to a series of price shocks in that duration. The Libyan apprising of 2011 together with tensions in Iran in 2012 may have contributed to the rise in oil prices for this period. The fall in oil price from September 2014 was due to decrease in the global economic activity as indicated by the decline in the global Purchasing Manage Index (PMI) in that period. This decrease was also felt in prices of commodities of other industries. This fall in price of oil may also have been due to increase in Shale oil production by U.S and also increase in oil production in countries such as Russia and Canada.

In line with the foregoing and in consideration of the views held by Baumeister and Killian that oil price shocks represent the difference between the expected price of oil and the actual price, four episodes of oil price surge and three episodes of oil price depression can be identified between 1980 and 2018. These are: January 1980 to May 1981 oil price surge caused by the Iran-Iraq war; August 1990 to December the same year price surge resulting from the invasion of Kuwait; October 2007 to September 2008 price surge due to oil demand crisis and a series of oil price surges between December 2010 and August 2014. Oil price depression episodes were witnessed between January 1986 and November the same year; February 1998 and May 1999 and also between July 2015 and August 2016.

The oil price shock episodes identified above were decomposed into series. The data series are the deviation percentages obtained by subtracting the actual monthly oil prices from the quarterly average monthly oil price expectations. Figure 4.34 presents oil price shock episode of 1980/1981 and the sharp episode of 1990. The two episodes had their oil price increase by at least 22 % for 1980/1981 and at least 27% for August - December 1990. The 1990 episode (figure 4.34b) was more sharp because it saw increases of up to about 85% in September 1990 from expected price. In 1980 episode lasted relatively longer with maximum price deviation of up to about 44% in April 1980.

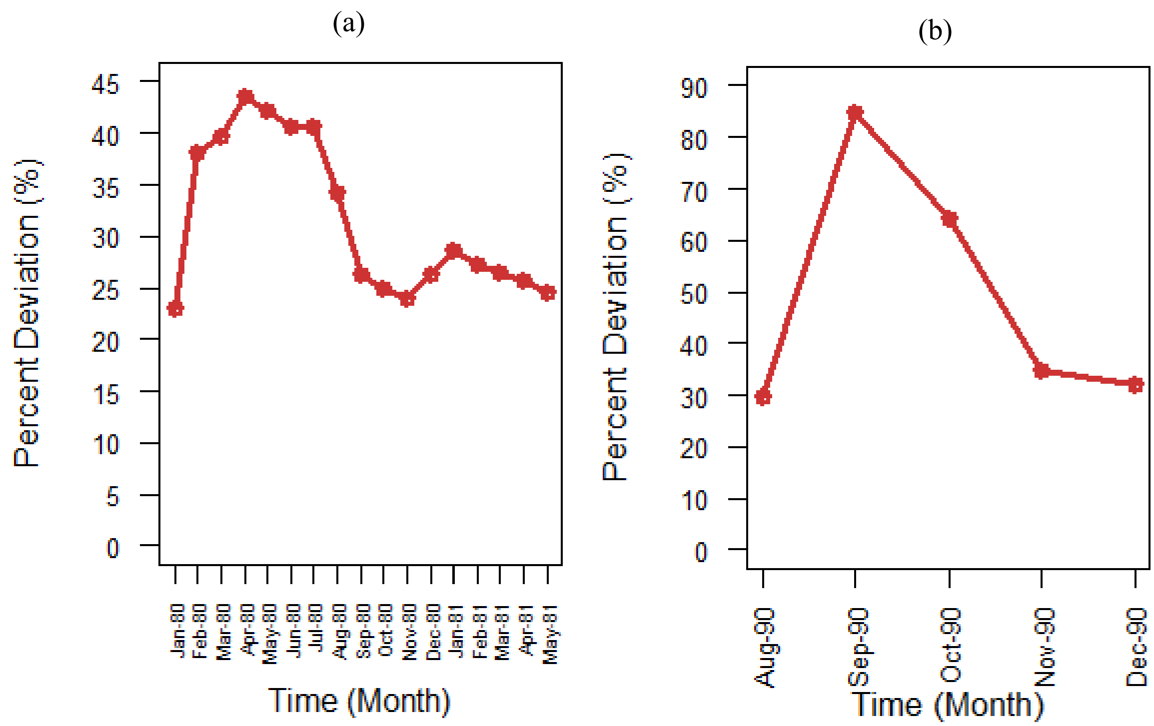

Figure 4.34: Oil price shock episodes of 1980/1981 (a) and 1990 (b)

The price shock episode of 2007/2008 in figure 4.35a presented another devastating spell in the oil industry where maximum prices of about 75% more than expected price we witnessed in the month of June 2008. During this episode, minimum oil price deviations were about 15% of expected price. Oil price slump or negative oil price shock episodes are those periods where oil prices fall way below price expectations.

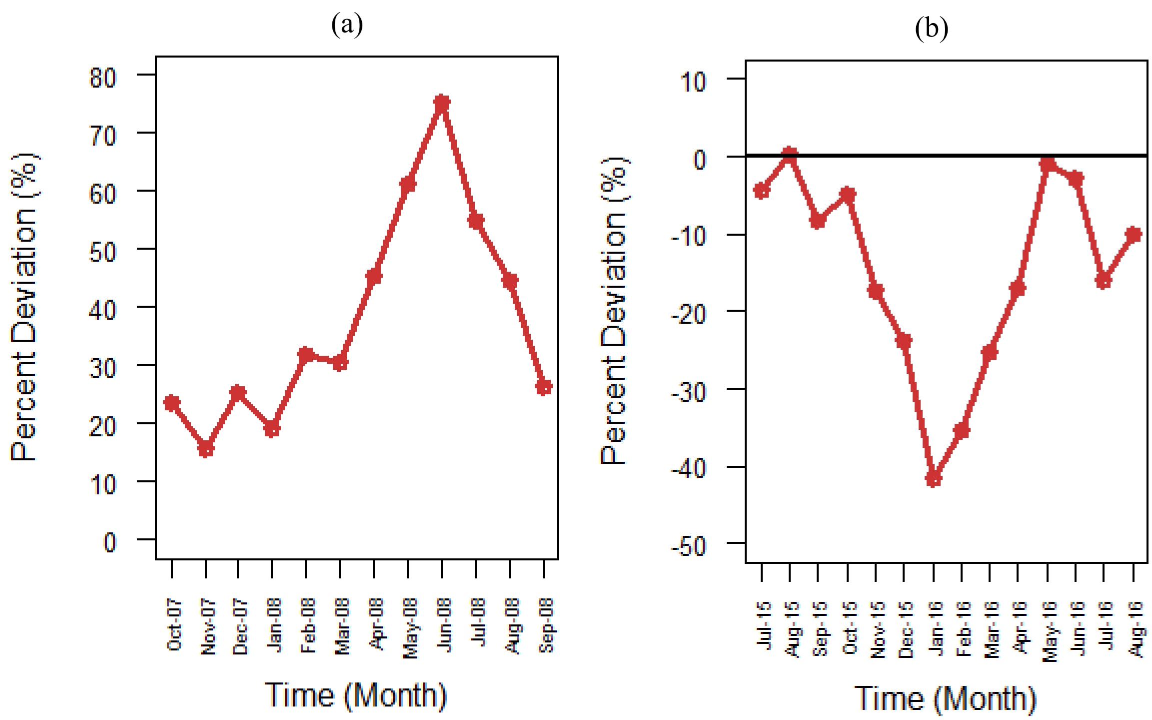

Figure 4.35: Oil price shock episode of 2007/2008 (a) and oil price slump episode of 2015/2016 (b)

The first such episodes over the duration of this analysis was witnessed in 1986 where all prices fall to their lowest levels by 53% during the month of March 1986 as shown in figure 4.36a.This episode lasted for 11 months with prices stabilizing towards the end of that year. The 1998/1999 figure (4.36b) episode was comparably similar to that of 1986 in terms of percentage deviation from expected prices. However, this episode lasted longer than that of 1986. The most recent oil slump episode was in 2015/2016 (figure 4.35b) that was characterised by about 44% decline of oil prices in the month of January 2016.

This episode was preceded by the prolonged oil price shock of 2011-2014. This oil price slump may be the results of the response to the preceding oil price shock by searching for more oil wells to address supply shortage thereby dealing a blow to the high oil prices. Figure 4.37 shows the prolonged oil price surge of December 2010 to August 2014. During this period there were a series of high oil prices with the extreme maximum occuring during the month of April, 2011 at a deviation of about 48% from price expectations. Oil prices remain and may continue to be difficult to predict because it is almost impossible to anticipate the exact time political crises will occur in the middle East to trigger oil crisis.

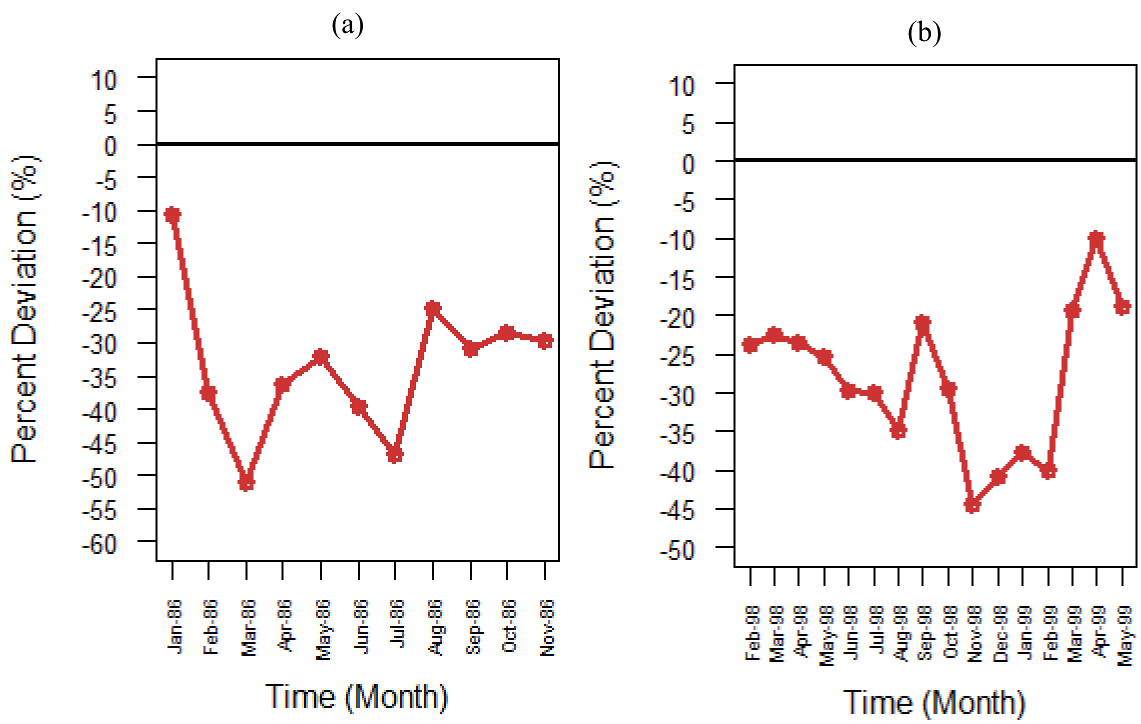

Figure 4.36: Oil price slump episodes of 1986 (a) and 1998/1999 (b)

Crises rarely occur but ignoring crises in oil price prediction models may cause serious errors and lead to predictive failures in case the unanticipated crises eventually happens.

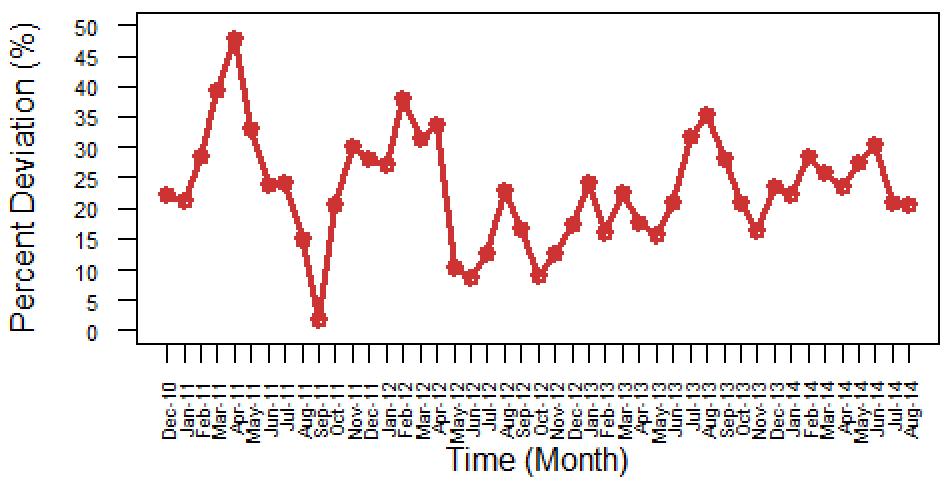

Figure 4.37: Oil price shock episode of 2010-2014

Economic crises such as the financial crisis of 2008 may also prove challenging for economists to foretell. From this analysis, it is observed that oil prices show high volatility with no long run trend.

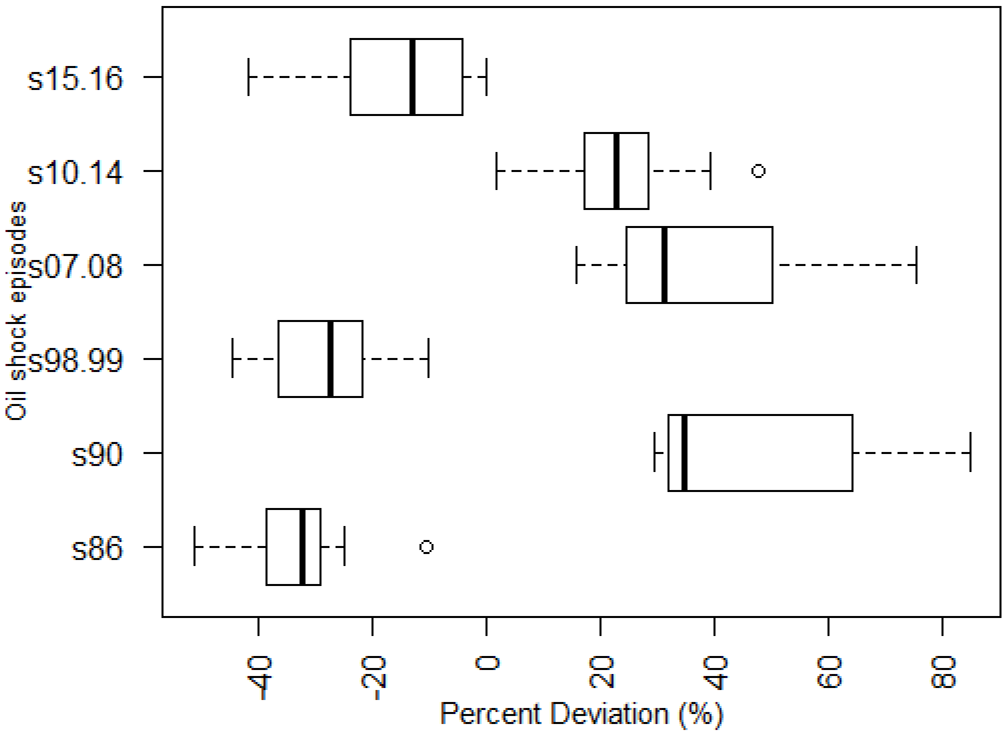

Figure 4.38: Box plot showing Oil price shock episodes

The box plot in figure 4.38 summarizes the oil price shock characteristics of the episodes discussed above. The oil price surges of 1990, 2007/2008 and 2010-2014 lie to the right while the price slump episodes lie to the left. The price shock episodes of 1990 and 2007/2008 had the highest price fluctuations while those of 1986 and 2010-2014 had the least price fluctuations as shown in figure 4.38

4.6.1 Oil Price shocks on Electricity Generation

Electricity generation in Kenya has quite a significant share contributed by thermal generation where diesel is the main fuel. Diesel, a crude oil product is affected by fluctuations in the world oil markets including its availability and the retail price. The consequences of surges and slump in oil prices are highly felt by countries that import oil and oil products. Importing oil for electricity generation may have severe consequences on electricity generation in case of price surges in the oil markets. The analysis below seeks to investigate and quantify the effects of price fluctuations in the oil markets to electricity generation.

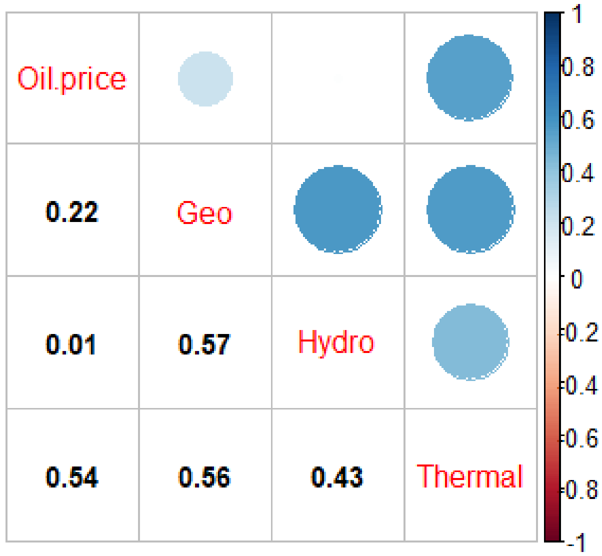

Figure 4.39: Correlation matrix between oil price and electricity generation

Thermal generation fluctuates in synchrony with oil prices and that low oil prices highly favour thermal electricity generation while oil price surges discourage ventures into thermal generation. This is confirmed by the correlation matrix in figure 4.39 where the correlation coefficient between oil price and thermal generation is 0.54 signifying a positive linear relationship. The main fuel for thermal generation in Kenya is diesel, a by-product of crude oil) where Kipevu I and III diesel generators have a combined installed capacity of 192.5MW. From the figure, oil prices and hydropower production does not portray any meaningful relationship with a correlation coefficient of just 0.01. Hydropower is mainly affected by hydrologic conditions. Geothermal versus oil prices yielded a correlation coefficient of 0.22 which is also too low to draw meaningful statistical inference about their relationship.

4.6.2 Oil Price Shocks on Electricity Price

In the next analysis, a discussion is presented on the association between oil prices and electricity prices. Electricity prices as discussed before, can reflect constraints in the underlying structure taking into account that generation costs are transferred to consumers. Energy sources such as hydropower, geothermal, wind and solar usually have low tariffs per kWh because of their low generation costs compared to thermal. However, the opposite is true for initial development costs, with renewable technologies costing more than thermal and other non-renewable.

Operation and maintenance costs are high for thermal generation because of fuel costs incurred during generation. In fact, the FCC component of electricity price is as a result of fuel costs incurred for thermal generation. This component is highly variable and constitutes about 40% of the total electricity price that is transferred consumers.

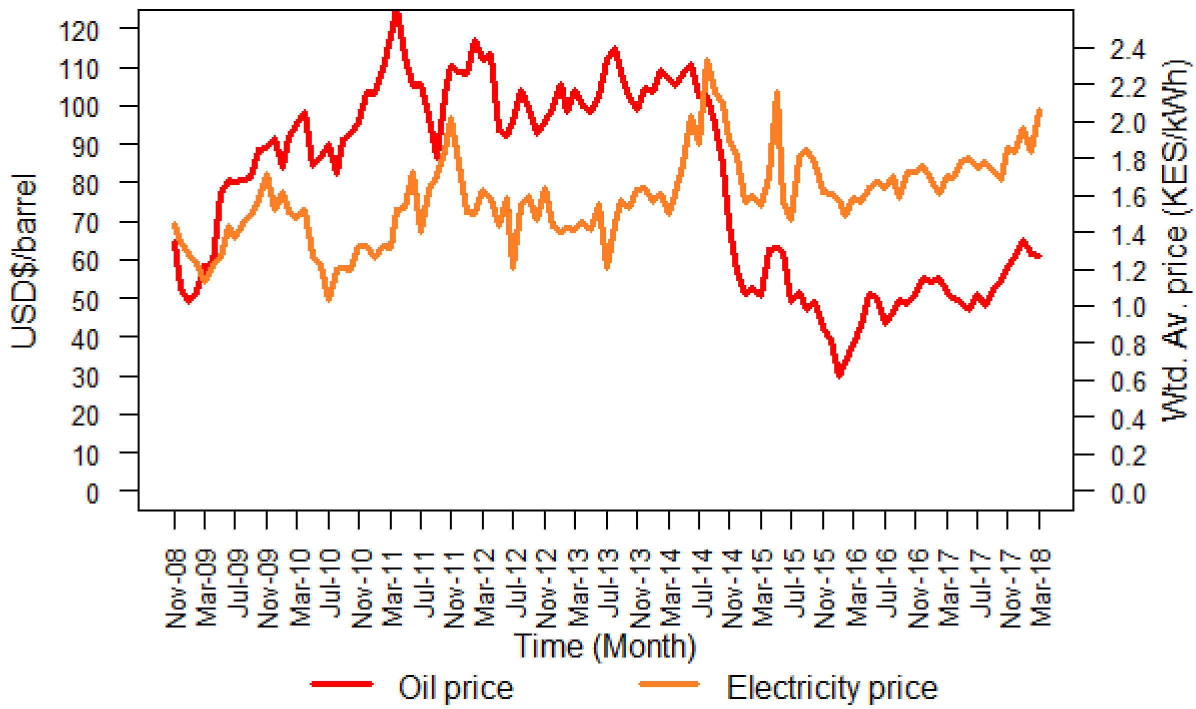

Figure 4.40:Graphs of oil prices and the weighted average electricity prices

In this analysis, monthly data from November 2008 will be utilized due to unavailability of past records. Weighted average electricity prices are observed to run parallel to oil prices in figure 4.40. Apart from the FCC component and the fixed charge cost, the other electricity price components are not as a result of electricity generation but they comprise managerial, legislative and authorization costs. The fixed charge costs include operation and maintenance costs of transmission and distribution lines and range between 2.5% and 3.5% of additional increase in gross investment plant (KPLC, 2013). Other includes charges for recovery of financial assets lost by the electricity utility and wayleave levies by government agencies. The burden of shifts in oil prices is therefore only shouldered by the FCC component which is second single largest component of electricity price after the fixed charge component. Electricity prices therefore are not solely dependent on oil prices but depend on a component which is affected by oil prices. Figure 4.40 shows this lack of synchrony between oil prices and weighted electricity prices indicating the effect of other price components discussed above.

From the figure, electricity prices increased in March 2014 during the 2014 oil price surge episode but the prices remained level even after the 2015/2016 oil price slump. It ought to be understood that electricity prices may still rise despite decline in oil prices because as discussed before, less than 40% of monthly electricity bill paid by consumers is due to generation charges.

However, in figure 4.41, the FCC component varies in synchrony with oil prices. This component represents generation charges incurred mainly by thermal electricity generators where diesel is the main fuel. As such, oil prices affect diesel prices leading to a corresponding effect on generation charges. These charges are transferred to consumers in their monthly bills and they reflect the global oil prices. The relationship between oil prices and FCC is best seen during the oil price depression of November 2014 all the way to November 2017 as shown in figure 4.41. During this period, the FCC component declined drastically parallel to the oil price limb before levelling off but increased again towards the end of 2017 following an increase in oil price. There were high electricity prices and public outcry during this period extending into early 2018. The significant influence of oil prices to FCC is confirmed by the correlation analysis presented in figure 4.42 below where a positive correlation coefficient of 0.74 was obtained between the two variables.

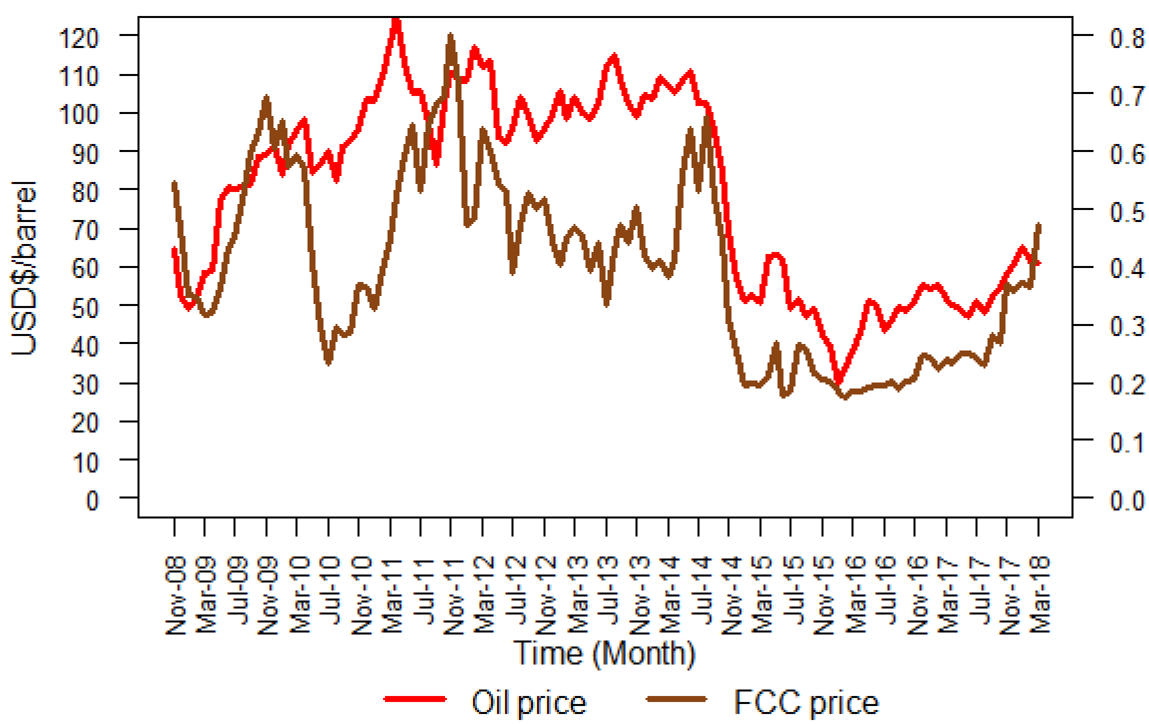

Figure 4.41: Oil prices against the weighted average Fuel Cost Charge component of electricity price

This huge correlation is shown by the large blue circle. Weighted average electricity prices are insignificantly influenced by oil prices while FCC relates with the weighted electricity prices by a partry 0.12 as shown below.

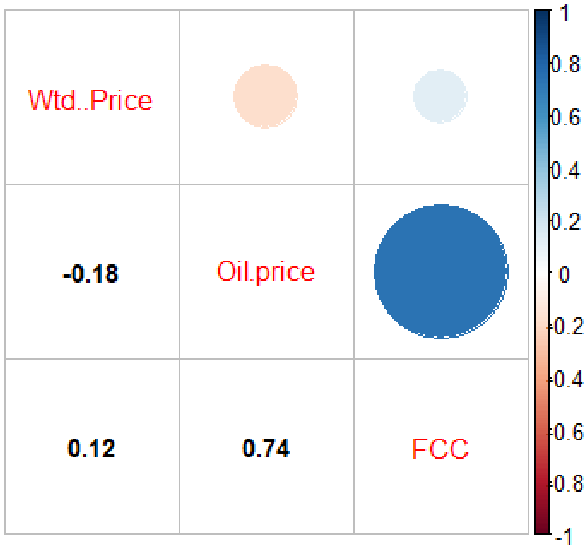

Figure 4.42: Correlation matrix between oil prices and electricity prices

The foregoing analysis reveals mixed effects of oil prices to the electricity sector. While thermal generation is totally influenced by oil prices, the renewable energy technologies (hydropower and geothermal) are hardly dependent on oil prices.

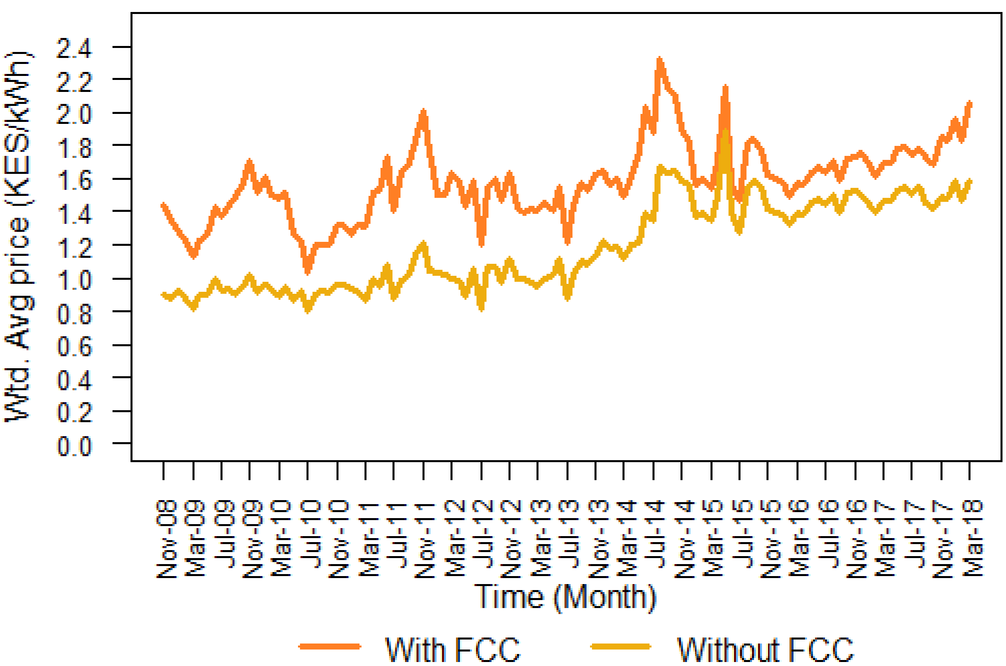

Figure 4.43: Weighted average electricity prices with FCC and without FCC

Eliminating the effects of oil prices on electricity prices through the FCC component can only be accomplished by elimination of thermal generation in the generation mix. The presentation in figure 4.43 shows a comparison of electricity price with the FCC component and without the FCC component. From November 2008 to November 2014 the difference between the two if wide before narrowing towards 2017 following the 2015/16 oil price depression. The wide gap shows the huge contribution of FCC to price while narrow gaps signify least impact of the FCC. It is noted that the impact of FCC on price is more significant during oil price surges and minimum during oil price slump.

4.7 Resilience metrics and electricity price

Electricity price can reveal meaningful information about the nature and structure of the electricity sector within a given locality. There is no clear definition of energy security and different authors have taken different approaches on this topic. Energy security entails threats that affect the supply chain of energy (Winzer, 2012). Not to be confused with sustainability which entails environmental impacts. A secure energy system is one that is able to provide energy that is affordable by the consumers. Price is therefore a key component in energy security and is an indication of the affordability of the energy provided to consumers. In this analysis, price is taken to be a measure of energy security. The capacity of the electricity sector to adapt to threats is also reflected in electricity price in cases where there are no government subsidies. If there is a disruption in electricity generation like a sudden increase in oil price, we expect this disruption to be reflected by increase in the price of electricity for that period.

A decrease in river flows will be accompanied by low generation from hydropower sources thereby necessitating ventures into emergency generation to satisfy demand. Emergency generation is mainly sourced from conventional fuel sources that are on standby and this increases the FCC eventually being reflected in the total price. In this section, the resilience metrics discussed earlier will be used as predictors of electricity price. Diversity is the metric for alternative energy sources available and it becomes useful in case of depressed generation from the main source. Spare capacity is useful in ensuring stability of supply in case of sudden rise in demand while the importation metric represents deficiencies or surplus.

4.7.1 Electricity Price versus Diversity Metric

In order to limit the production cost risks associated with fuels such as oil, coal and natural gas whose future prices remain uncertain, a diversified energy sector is more effective in minimising the cost of production risks. Diversity is therefore the best cost risk management strategy to countering the highly volatile oil sector and the uncertainties surrounding future climate scenarios that may affect hydropower availability. The current diverse generation mix in the Kenya power sector has evolved over time because of different factors which include the decisions made by policy makers long ago, technological capabilities and the decommissioning of old power plants. Diversification of generation mix ought to be done with the aim of achieving the most cost effective generation mix.

However, the benefit of diversity from some fuels increase as the share of the fuel in the portfolio decreases. For instance, diversifying the energy sector by addition of oil in the generation mix does not benefit the energy sector as oil might not withstand the environmental regulations that will be tightening in the future. There has been growing unpopularity in the use of oil, coal, nuclear and hydropower as part of the generation mix compared to other renewables. This has been due to strict environmental regulations against oil and coal with nuclear energy facing diplomatic issues while hydropower has come of age and is more affected by the changing climate. The future of energy is likely to be dominated by solar, geothermal, wind and bioenergy.

Kenya has made advances in geothermal and wind while solar is mainly utilized as off grid under the REP and the M-KOPA program. However, Kenya has shown intentions to include nuclear and coal in its energy mix. The two fuel sources are considered cheap sources of electricity and have been tipped to lower electricity costs to consumers. It ought to be noted that more energy diversity does not necessarily imply low electricity prices to customers. The types of fuels in the diversification have more bearing to the price than just their number.

The fuel options readily available in Kenya for generation have historically been hydropower, geothermal and thermal. In this generation mix, thermal has been used to substitute hydropower in events of poor hydrology. Such a generation mix does little to address the consumer prices since the alternative option (thermal) is costlier and is also a subject to the highly volatile oil prices. Diversity with respect to the Kenya energy sector especially the electricity sub-sector has therefore not been able to address the ever high electricity prices and this has continued to rise despite injection of more power from geothermal. From figure 4.44, the graph of diversity runs almost parallel to that of electricity price with the two portraying a positive linear relationship at many points apart from a few isolated points.

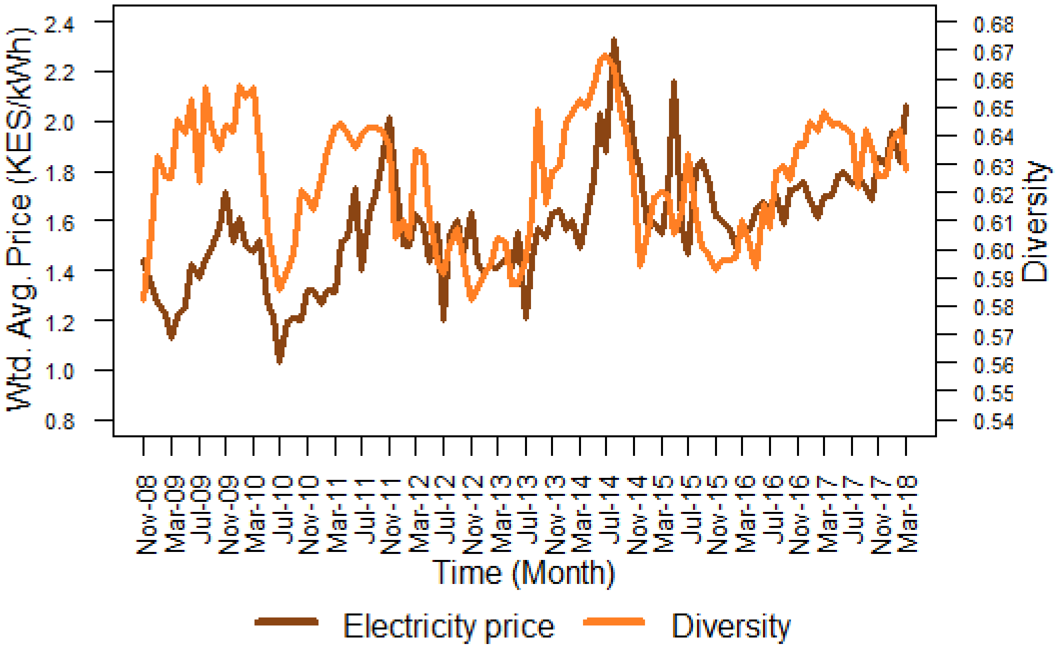

Figure 4.44: Weighted average electricity prices against diversity indices

However, with the addition of more fuel sources in future, most likely coal and wind according to the current trends in the public policies of the energy sector, this trend is likely to change significantly. Unlike oil, coal is not affected by volatility in prices and it may be sourced locally. An option to stabilizing electricity prices in Kenya is by removing the FCC component which can be achieved by getting rid of diesel power plants and through policy incentives to encourage competition and more renewable IPPs.

4.7.2 Electricity Price versus Spare Capacity Metric

Spare capacity may represent reserves in the installed capacity and it is necessary in ensuring that the power system is able to respond to load increase. As such, the installed generation capacity (considering the capacity factors) has to be more than peak demand at any given time. Spare capacity is also referred to as planning reserve margin (US Department of Energy, 2016) in some literature and it represents the capacity which the power utility holds in reserve and which can be utilized in cases of threats to the system due increases in the load. The reason for having spare capacity is that there is no power plant that can be 100% reliable and that there may be uncertainties in load forecasting leading to higher load than anticipated. The spare capacity is a representation of the amount of capacity available above the demand. In this analysis, this amount is standardized using the $2016 GDP. Low or no spare capacity is detrimental to the power system while a depreciating spare capacity is an indication of strain or threat to the power system.

This threat is likely to be reflected in the price especially where the spare capacity is held in costly fuel source as is with the Kenya case.

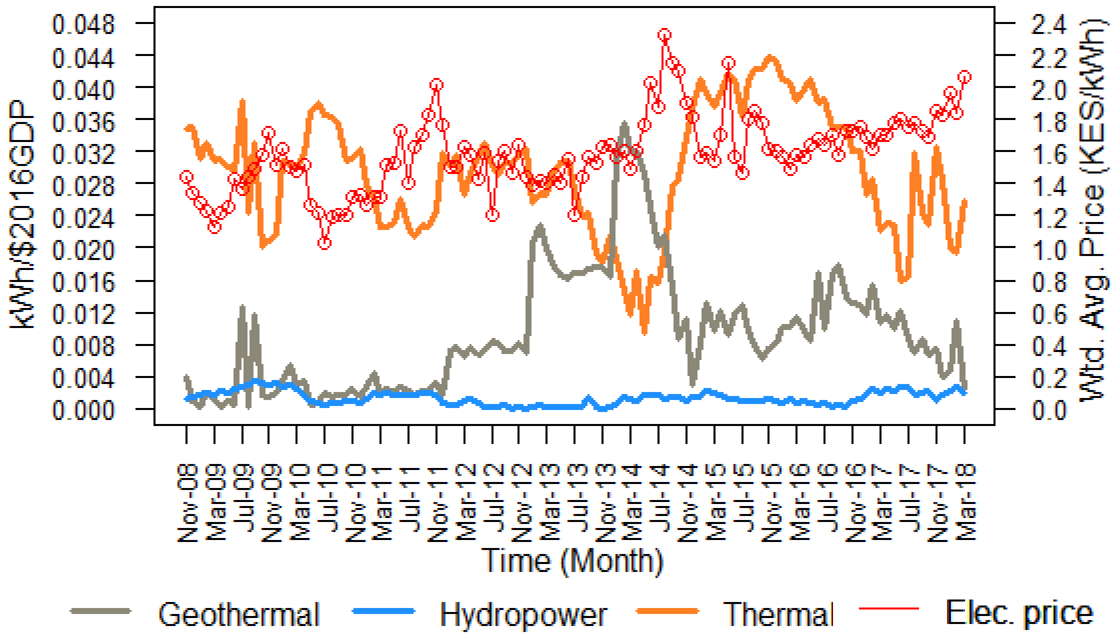

Figure 4.45: Spare capacity from selected electricity sources against weighted average electricity price

Figure 4.45 shows conventional thermal holds the vast majority of spare capacity in the Kenya's power sector, geothermal is moderate while hydropower has the least spare capacity owing to its dominance of the power sector. Conventional and geothermal spare capacities have been used to maintain the system reliability with conventional thermal generators stepping up for hydropower deficiencies. From the graphs in figure 4.45, thermal spare capacity graph runs opposite to that of the weighted average electricity prices from the period November 2008 to March 2018.

The high electricity price episodes of November 2011, July 2014 and 2017/2018 all coincide with reduction in thermal spare capacity. A reduction in thermal spare capacity implies increasing utilization of the fuel which attracts more costs in form of FCC. The period November 2016 to March 2018 was marked by increasing spare capacity in hydropower and decreasing spare capacities in thermal and geothermal signifying higher utilization of the latter energy sources over that duration. A corresponding increase in electricity price is marked during that period. Spare capacity is also necessary in determining the frequency of blackouts and electricity operators have the task to determine the threshold in spare capacity that will guarantee the least or no blackout occurrences.

The type of resource that is put in place to provide the capacity needed to respond to threats such as rapid load increase is of utmost importance. A resource such as conventional thermal has traditionally been effective in responding to such threats but detrimental to the consumers in terms of price as is with the Kenyan case. Electricity demand is projected to increase implying load growth thereby calling for electricity utilities to plan for maintaining the adequacy of the electricity sector. Other than increasing conventional spare capacity, plans such as energy efficiency and lowering peak demand may be suitable for maintaining the reliability of the electricity sector.

4.7.3 Electricity Price versus Import Metric

Electricity importation in many instances is mainly to cater for electricity shortfall and system stability. Maintaining a sufficient reserve capacity in electricity generation to meet demand surges in stochastic demand may not be straightforward. Electricity imports from neighbouring countries that have resource advantage may serve to reduce keeping excess reserve capacity. Where domestic generation cannot sufficiently meet domestic load, it may be more economical to import electricity from markets where prices are low compared to the domestic opportunity cost of generating electricity. Importing electricity from markets where prices are relatively higher may be more disadvantageous. The situation in Kenya has been worsened by the fact that Kenya has been importing electricity from Uganda which is much costlier than electricity generated locally from hydropower. An agreement signed in 2014 between Kenya and Uganda set the price of KES 21 for cross-border purchase of electricity between the two countries. Kenya had hoped to sell more power to Uganda in order to benefit from the agreement but Uganda ended up to be the beneficiary of the higher tariffs as a result of increased exports to Kenya especially in 2014 and 2016/2017 as shown in figure 4.46.

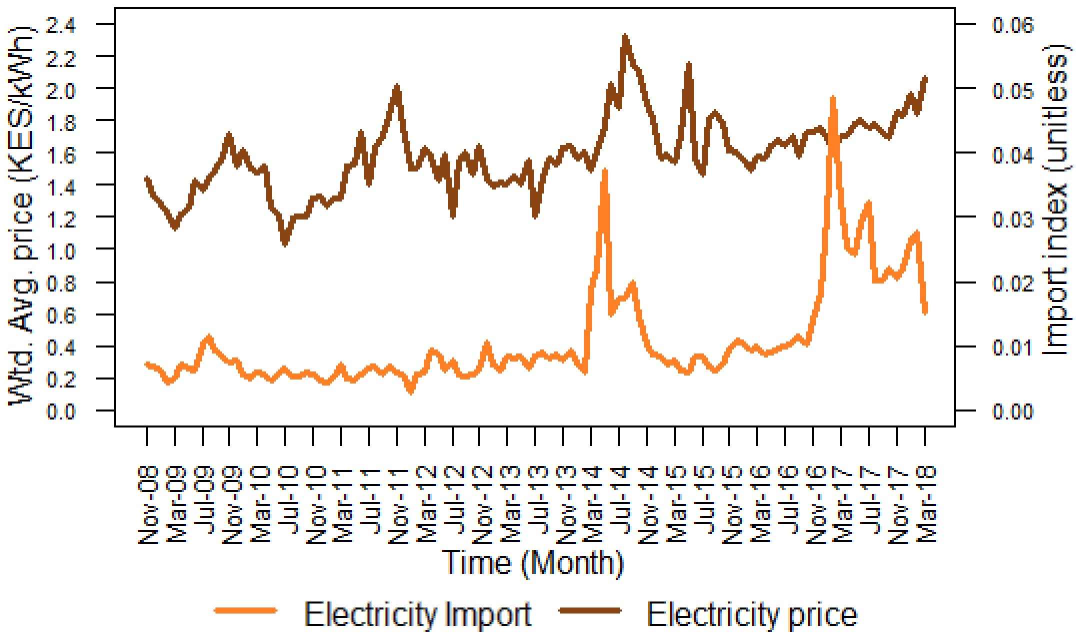

Figure 4.46: Graphs of the weighted average price against electricity imports

During these periods especially in 2014, electricity prices in Kenya increased considerably owing partly to increased local thermal generation and also due to increased expensive electricity imports mostly from Uganda. Increased imports from late 2016 may have contributed to the high electricity prices during the period 2016-2018 (figure 4.46).

The metrics discussed above have a bearing on the electricity price that is charged by the power utility in Kenya. The relationship between these metrics and electricity price have been summarized in figure 4.47. Electricity imports have a relatively strong positive correlation with electricity price at 0.43 while diversity is at 0.31. The scenario in Kenya is such that diversity tends to be positively correlated with price implying that increase in diversity leads to increase in price and this has been discussed earlier.

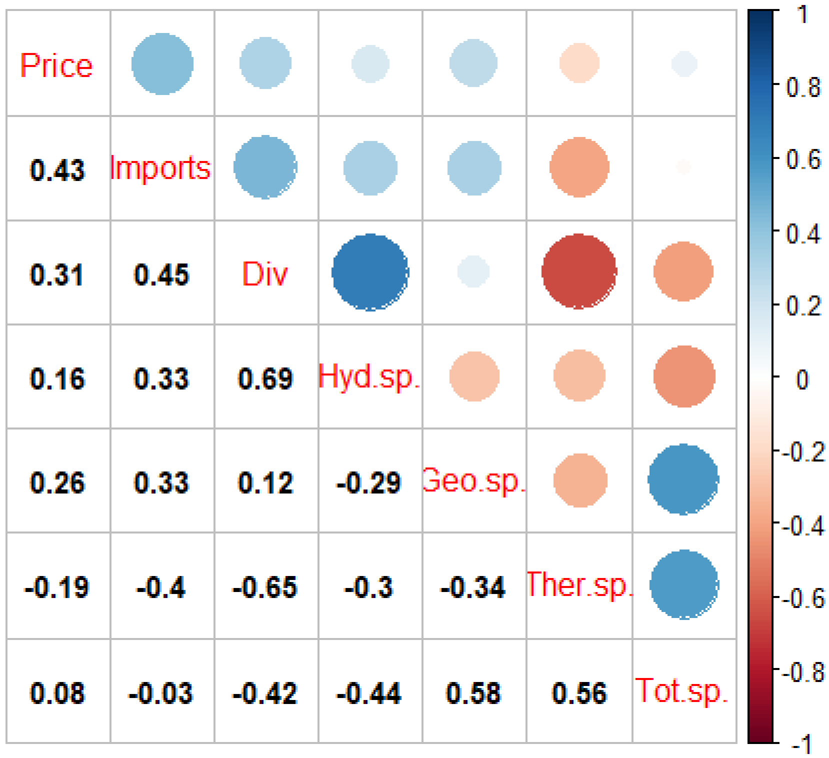

Figure 4.47: Correlation matrix between electricity price and resilience metrics

Among spare capacity of individual power sources, hydropower and geothermal have positive correlation with price while thermal generation has inverse relationship with price. The total spare capacity seems to be insignificant with a correlation of only 0.08 and may not be effective in predicting electricity prices. This is because of the combination of positive correlations of hydropower and geothermal and the negative correlation from thermal. Therefore, individual power sources will be considered under spare capacity. P-values of $8x10^{-4}$, $4x10^{-2}$ and $6x10^{-3}$ for diversity, thermal spare capacity and geothermal spare capacity imply that we cannot accept the null hypothesis that there is no correlation between the variables and electricity price.

4.8 Empirical Statistical Model for Prediction of Electricity Price

The coefficients for resilience metrics in predicting electricity price are presented in table 7. In this model, the coefficient of each attribute reflects the effect of that attribute on the prediction. An attribute with a coefficient 0 or near 0 has no effect or minimum effect to the dependent variable. The standard error measures the average amount that the coefficient estimates vary from the actual average value of the response variable (price). Diversity and thermal spare capacity were found to be of little effect while the import metric was found to be statistically significant.

However, the little effect of diversity and thermal spare capacity could be due to multicollinearity between the two variables. Diversity and thermal spare capacity have a correlation of -0.65 between them and are therefore highly correlated as shown.

Table 7: Regression Analysis of Resilience metrics and electricity price

Dependent variable	Weighted average electricity price (Nov 2008 – March 2018)			
Number of Observations	113			
Method	Least Squares			
Multiple R-squared	0.2038			
Adjusted R-squared	0.1819			
F-statistic	9.302			
Residual standard error	0.2125			
Degrees of freedom	109			
p-value	1.576e-05			
Resilience Metrics	***Coefficients***	***Standard error***	***t-value***	***Statistically significant***
Electricity Import	10.9671	2.8528	3.844	Significant
Diversity	1.3671	0.8162	1.675	Significant
Thermal Spare Capacity	2.6901	3.5263	0.763	Insignificant
Intercept	-0.0473	0.9127	-0.052	

In figure 4.48, the standardized anomalies of the model output data are tested against the standardized anomalies of observed data. For standardized values, the expected weighted average price becomes 0. It is observed that between November 2008 and March 2014, the price anomalies were below the expected price while July 2014 to March 2018 experienced above normal prices. This observation is true for both actual and predicted values. This model may therefore be used to anticipate general trends in electricity prices over certain periods of time.

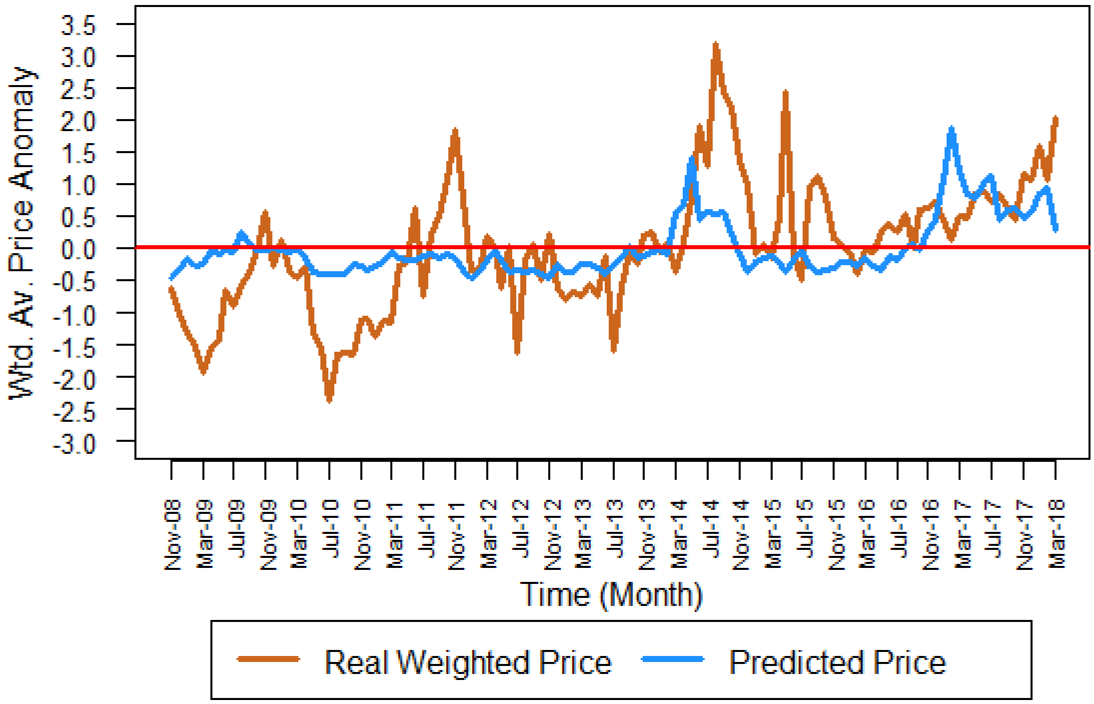

Figure 4.48: Real versus predicted electricity prices

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This study utilized a total of 4332 data points from 36 datasets and 5 data sources to relate and draw inferences among different variables. Fast variables are variables with short turn over times and have a profound effect on the availability of electrical energy in a country. The fast variables under consideration were oil shocks, electricity prices and weather while climate is a slow variable. Resilience metrics in the form of diversity, spare capacity and system effectiveness are presented as quantitative measures of resilience. Electricity generation in Kenya has greatly relied on hydropower for long until recent ventures into geothermal and other renewable energy technologies shifted the generation mix. Increasing inter annual trends in renewable sources apart from hydropower have marked increase in total electrical energy generation while thermal generation remains a contingency plan. Hydropower has been on the decline in recent years. Electricity generation undergoes seasonal patterns with hydropower acting in synchrony with rainfall seasons. Therefore, making use of rainfall predictions may be used in the stabilization of the energy sector.

The electricity sector in Kenya has become more diversified than before owing to addition of more generating capacity from wind and geothermal. Thermal forms majority of spare capacity while installed hydropower has been utilized to almost full capacity. Price of electricity in Kenya is linked to electricity generation in a linear relationship in that that increase in electricity price leads to stepping of electricity generation. Global oil prices have a bearing on the electricity price through the Fuel Cost Charge charged as a result of thermal generation. Oil price shocks have occurred in the past and have been found to affect thermal generation and therefore increase electricity prices. Electricity generation is also affected by global oil prices with more thermal generation in periods of low oil prices and less generation from thermal in oil price crisis periods. Electricity imports and the diversity metrics have positive significant correlations with electricity price while spare capacity is weak in determining price. Nevertheless, thermal spare capacity inversely affects price in that increase in thermal spare capacity leads to decrease in electricity prices. Therefore, electricity prices can go down if we increase thermal spare capacity by putting in place a policy to regulate thermal generation.

Weather and hydropower are closely linked and the effects of climate change are likely to have a great impact on hydropower. Erratic rainfall that is irregular and sometimes unpredictable casts a doubt on the future of hydropower and its reliability as a renewable energy source. Hydropower generation in Kenya from water reservoirs is highly dependent on rainfall. Periods of low rainfall are marked with declining generation from hydropower and increasing generation from thermal sources. Overreliance on hydropower may be the genesis of the problems faced in the electricity sector in Kenya especially high electricity prices and frequent power shortages. At lags 2 and 3, hydropower and rainfall portray a positive relationship. Improved predictability of rainfall can lead to timely planning in the electricity sector by anticipating shortages or enhanced hydropower generation. This will lead to informed decision making regarding importation and thermal generation.

Diversity and the imports metrics have a significant role in the statistical model for predicting electricity prices. Diversity shows positive correlation with electricity prices implying increased diversity leads to increase in electricity prices. It is also noted that thermal generation has a bearing on diversity in Kenya due to its periodic fluctuations and persistent use. Diversifying the generation mix by thermal generation sources may therefore not be beneficial to electricity consumers as this affects price negatively. The imports metric serves to give an indication of internal deficiencies that result from external factors such as oil shocks and also climate change signals. These factors cause shortfalls in electrical energy that is compensated by importation from neighbouring countries. Electricity imports could therefore be a reflection of the external disturbances and climate change signals. Therefore, Imports and price have a positive association where increase in imports raises electricity prices. The statistical model explains about 20% of the variation in electricity prices and is to be used with caution. This model is a least squares regression model and it seeks to utilize the relationships between the resilience metrics and electricity price to determine price outcomes in different energy scenarios. This study has quantitatively established the role of the three-resilient metrics; diversity, spare capacity and system effectiveness in predicting electricity price as a measure of resilience in electricity generation.

a) Households

In the year 2017, about 55% of Kenyan households were connected to the national grid with the country planning to achieve ‘universal access’ (95%) by 2020 according to the Kenya School of Government Strategic Plan 2016-2020. Most studies have attempted to explain and design development of efficient technologies in buildings that are targeted at encouraging households to minimize energy consumption. Several policies have also been put in place to regulate the use of energy by Kenyan households. However, these attempts to conserve energy use in households have seen little success. One reason for this is the limited information regarding the underlying fleet structures to electricity consumers. Availability of information such as the anticipated prices of electricity might compel households to regulate their electricity consumption to avoid high electricity bills. People consume more because they can afford it. On the other hand, improved energy efficiency by electricity utilities and increased energy diversity will make energy cheaper and thereby encourage electricity consumption within households. Another reason why efficiency based approaches to energy conservation in households have failed is because of psychological biases and social understandings among consumers. If for example, people feel that they have done something to save energy, like buying an energy efficient bulb, then they might feel that they do not have to care so much about how they use it. However, if they anticipate that the price paid for using the appliance will increase, they will tend to care so much how they use the appliance out of abundance of caution.

b) Entrepreneurs

Entrepreneurs always look for business opportunities they can venture in to provide essential services for purposes of profit making and for future investments. Therefore, background information is important in deciding or selecting profitable investments. The energy sector offers great opportunities for prospective entrepreneurs who wish to invest in electricity generation as independent power producers (IPPs). This study will aid them in identification of better energy options among many alternatives. The better energy option for investment may be the one which is least vulnerable to disturbances such as extreme weather or fluctuations in oil prices. Entrepreneurs who have or plan to invest in energy intensive projects such as wielding may regulate their businesses to ensure peak operations during periods with low electricity tariffs. Improvements in energy efficiency and increased diversity will make their services cheaper hence more demand for the services.

c) Public Officials – Policy makers

Governance forms an integral part of the energy sector. Policy contexts made by policy makers influence the use of various energy resources and the energy infrastructure. This study provides insights into historical relationships between energy structures and price thus providing the base knowledge policy makers need for future projection of possible factors that might influence energy prices. Future energy governance also requires information on the interaction between the energy structures and the natural environment such as weather and changes in climatic conditions. Such information will enable policy makers to formulate energy policies that ensure robust and resilient energy systems. For electricity generators, it may be more important to know how much spare capacity is in stock and the options that exist for backup power generation.

It will be possible for policy makers in the energy sector to understand the mechanisms behind a secure energy future and also understand the dangers of over reliance on importation of fuels for electricity generation while appreciating diversification of energy sources. The energy consumed during electricity generation remains at large while the significance of system losses on electricity price is not clear. This may be an area for further studies.

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APPENDIX I : R-SCRIPTS

```
data<-read.delim(file="name.txt",header=T)
x<-as.vector(t(as.matrix(data[,1])))
y<-as.vector(t(as.matrix(data[,2])))
plot(y,type="o",pch=1,lty=1,bty='L',col="brown3",lwd=3,axes=F,xlab="Time (years)",ylab="Billion Kilowatthours",cex.lab=1.2)
axis(1,at=1:length(y),labels=x,cex.axis=1.2)
axis(2,seq(0,37, by=0.1),las=0.1,cex.axis=1.2)
lines(hydro,col="dodgerblue1",lwd=3,type="o")
lines(bio,col="green4",lwd=3,type="o")
lines(solar,col="chocolate1",lwd=3,type="o")
lines(wind,col="cadetblue1",lwd=3,type="o")
lines(thermal,col="darkgoldenrod2",lwd=3,type="o")
box()
abline(h=0, col="red",lwd=2)
plot(y, type="o", col="blue", lwd=4, axes=F,xlab="",ylab="")
axis(2)
par(new=TRUE)
plot(y3, type="o", col="red", lwd=4, axes=F,xlab="",ylab="")
axis(4)
axis(1,at=1:length(y1), labels=x)
mtext("Number of thunderstorm days", side=4,line=1.5)
mtext("Number of flight incidents", side=2,line=2)
legend("topleft",col=c("brown3"," dodgerblue1","chocolate1"),lty=1,legend=c("Geothermal","Hydropower","Solar"))
title(xlab="Time (months)")
box()
barplot(matrix(c("data"),nr=2),xlab="Year",ylab="Consumption (Billion kWh)", beside=T,col=c("aquamarine3","coral"),names.arg=c("data"))
legend("topleft", c("Domestic & small consumers","Large & medium commercial"), pch=15,col=c("aquamarine3","coral"),bty="n")
library(corrplot)
M <- cor(data)
corrplot.mixed(M)
corrplot.mixed(M, lower.col = "black", number.cex = .9)
timeseries<-decompose(y)
timeseries$trend
timeseries$seasonal
timeseries$random
plot(timeseries,col="dodgerblue1",lwd=2)
library(TTR)
SMA3<-SMA(y,n=3)
boxplot(data, horizontal=TRUE, main="Proportion of units sold",axes=F)
boxplot(dev[,-1], horizontal=TRUE, main="Oil Shocks")
model<-lm(price~diversity+sp.capacity+imports,data=data)
summary(model)
predict <- predict(lm, newdata = data)
```

APPENDIX II: EXPENDITURE

	Item description	Duration/quantity	Unit price (USD)	Cost (USD)
1	**Travel**			
	Return ticket to Nairobi			86,044 DZ $782.22
	Local transport (supervisor meetings, data collection and internship)			67,500 KES $703.125
	Transport (Tlemcen - Algiers)			6000DZ $54.54
2	**Research Equipment, Material and Services**			
	Subscription to CEIC Data	4 months	$229.00 per month	$916.00
	Oil prices data		$4	$4
	Internet subscription fee (Safaricom)	4 months	10,000 KES	40,000 KES $416.67
	Printing (coloured) and binding	6 copies (96 pages each) Binding	20 KES per page 100 KES per copy	11,520 KES $120 600 KES $6.25
	TOTAL			**$3,002.805**

Conversion rate: 1 USD = 96 KES

1 USD = 110 DZ