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GEOTHERMAL ELECTRICITY COMPARED TO ELECTRICITY FROM OTHER SOURCES IN KENYA

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DECLARATION

I, Samo Teddy Miller, do hereby declare that

1. I am the sole author of the master thesis "Geothermal Electricity Compared to Electricity from other Sources in Kenya"- Assessment of both generation costs and sources potential together with benefits derived from geothermal power generation, and that for the study I have not used any source other than those referenced.
2. I have not prior to this date not presented the above named master thesis to any examination board for award of a master degree in any university.

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I confirm that this master thesis has been submitted for examination with my approval as the University Supervisor.

Signature ______________________________ Date ____________________________

Professor Pall Valdimaersson

DEDICATION

I dedicate this research work to my wife, mother and father for their limitless support, understanding and their continued prayers in allowing me pursue this MSc. program.

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Abstract

Kenya's energy mix is predominantly renewables; more than 80 percent of electricity is generated from locally available renewable sources. To lessen the pressure put by economic growth on the electricity supply and to meet the growing electricity demand, Kenya is planning to generate electricity from non-renewable sources. A number of literature exists on energy sources potential in Africa and a number of studies on renewable sources in Kenya. Nonetheless, currently there are no inclusive studies on cost and energy sources comparison in Kenya therefore this thesis seeks to fill this gap. This thesis analyses the potential for the energy sources in Kenya. Further it calculates using LCoE model the levelized cost of electricity for different energy sources (geothermal, hydro, wind, solar, biomass cogeneration, natural gas, coal and nuclear). For robust results, sensitivity analysis is carried out on the effects of discount rates, ranging from 7% to 14% are used, also considered in the sensitivity analysis are the effects of plant economic lifetime and percentage increment in investment costs. Based on the analysis results of this report, renewables sources are economical with geothermal being the most economical of all in Kenya. Finally, this thesis discusses the benefits associated with continued use of geothermal heat for electricity generation grouping the benefits into economic and environmental benefits.

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LIST OF ABBREVIATION AND ACRONYMS

EIA – Energy Information Administration

ERC – Energy Regulatory Commission

GDC – Geothermal Development Corporation

GHGs – Green House Gases

GWh – Giga Watt Hour

GDP – Gross Domestic Product

IPPs – Independent Power Producers

KENGEN – Kenya Electricity Generating Company

KENTRACO – Kenya Electricity Transmission Company

KPLC – Kenya Power and Lighting Company

KWh – Kilo Watt Hour

LCoE- Least Cost of Electricity

IGA – International Geothermal Association

MJ/Kg - Mega joules per kilogram

MW – Mega watt

PPM – Parts Per Million

UNDP – United Nation Development Programme

WHO – World Health organisation

1 INTRODUCTION

For both technological and economic development, electricity is the most desired, as it plays important role in driving the industrial sector. Energy is a vital contributor to quality human life both directly and indirectly. Energy use stimulates social amenities improvements, job creation, health care, improved medical facilities and food preservation, better education and lastly improvement in information technology.

The ever expanding demand and increasing energy consumption in the world has put pressure on fossil fuels leading to their depletion and global warming associated problems. These challenges necessitate the need to manage and use available renewable energy resources in an appropriate manner.

The need to cut down GHG emissions by 80% to stabilize climate change at a moderate 2^oC temperature rise by 2050 and the depletion of the fossil fuel reserves possesses great challenges to countries depending on conventional sources, Kenya being one of them has to undergo major changes in her energy sector in ways of her sourcing for energy. With this situation at hand these country's energy policy makers need a guide for selecting the best technologies to harness the much needed energy to meet growing demands. Moreover, investors are constantly facing difficulties on technical choices related to renewable energy and optimal specifications for the different locations.

The aim is to achieve insignificant emissions of CO_2 gas, constituting the largest share of GHGs emissions, achieving this will lead to a much safer and friendlier environment. This has necessitated the use of techniques that saves on energy as well as better environmental protection measures realizable through reduction in energy consumed and intensive use of renewables to generate the energy. Energy needed for rapid development can be provided by renewable energy across the world. In the recent years, commonly used green energy sources were wind and solar, though the use of geothermal has been gaining ground mainly in countries with this resource (Klychev, 2007).

In Kenya three energy resources primarily defines energy mix: biomass, petroleum and hydropower. As at 2010 the installed capacity was 1429MW, hydroelectric power had the highest percentage at 52.1%, followed by thermal plants at 32.5%, geothermal making 13.2%, wind and others stood at 2.2% (Hivos people unlimited, 2011). There exists a high energy potential mainly renewables in Kenya. Biomass forms the largest form of primary energy supply accounting for about 74%, some of the resources have limitedly been exploited case example being geothermal. Geothermal resource has only seen large scale application. Small scale application of Geothermal for electricity generation, direct use and ground heat for cooling and space heating have not been ventured extensively.

1.1 Kenya Background

Kenya is located within East Africa and it shares her boundary with Tanzania in Southwest, Uganda to the West, Somalia to the East, southern Sudan and Ethiopia towards the North and a coast line that stretches to about 536 kilometres lengthwise ashore Indian Ocean. It covers area of 580 367 km^2 of which 11 227 km^2 is covered by water bodies (CIA, 2015). Kenyan Rift valley is located on the west and central part, it dividing the Kenyan highland into two. Agricultural activities in the country are concentrated at this location due to fertility of land and good climatic conditions. Nearly all of the geothermal activities are sited in the Kenya's Rift.

The arable land covers less than 10% of the total area, with a permanent crop cover of 0.9% and has forest cover of 6.1%, (CIA, 2015). Kenya has a number of rivers some of which has been used for electricity production, most of these rivers drain into Lake Victoria while others drain into Indian Ocean. Rivers Nzoia, Gori and Yalla drain in Lake Victoria. Tana River and Athi river flow across the south-east then drains to the India Ocean.

As at July 2015, the population of the country Kenya was 45 million, a big proportion is taken up by the youth whose median age is 19 years (CIA, 2015). A whopping 42% of the inhabitants comprises of youths under the age of 14, 33 % of the population lies between 25 and 54 years old and population growth rate of 1.93%. Increase in population continuously experienced in the country has a direct effect on the electricity demand; the electricity consumption in 2012 was 6.627 billion kWh, this is probable to increase as the economy of the country grows (CIA, 2015).

Only quarter of inhabitants in Kenya have electricity access. Availing electricity to the messes will comparatively bring out the difference between subsistence and back breaking labour in farming sector and improvement of technology that would results to a higher produce. Electricity access is considered key in poverty eradication, the government through the Rural Electrification Authority has gotten into a process of extending the grid to the interior and also creating off grid infrastructures in isolated zones. Sufficient provision of reasonably priced electricity to the population will stimulate sustained growth in economy and creation of employment opportunities to the youth.

In 2012/2014 there was 9.3% increase in generation of Electricity in Kenya from 8087GWh to 8,840GWh with peak demand of 1512MW compared to the previous peak value of 1463MW. Customer growth recorded 18.7% increase of in 2014. This increase in demand is attributed to the increased rural electrification rate and normal economic growth (Republic of Kenya, 2015).

It is observed that 80% of electricity in Kenya comes from renewable sources (Kiplangat, R.Z, & Li., 2011). By March 2015 the total installed capacity was 2177MW; a larger percentage was from hydro power plants. Of the total installed capacity, 820.6MW came from hydro, 717MW from thermal, 588MW from geothermal, wind and cogeneration had installed capacity of 25.5MW and 26MW respectively (Republic of Kenya, 2015). Even though hydro power currently account for a superior percentage of the whole power generation sporadic droughts in the country affects its viability.

There is an intensive expansion of the national grid and creation of off-grid network in Kenya driven by rural electrification initiative under the Ministry of energy. This expansion has resulted into an increase in the electrification rate to 30% as at 2014 (Climatescope, 2014). The government through Rural Electrification Authority is working to ensure increased accessibility of electricity to her population as is included in her vision 2030 to achieve objective of 40% accessibility by 2024.

Electricity generation in Kenya is liberalised and many producers are licenced to produce electricity for commercial purposes. KENGEN accounts for 70% of the installed capacity, the other 30% is taken up by independent power producers. By June 2015 81.3% of generated electricity in Kenya was from renewable (Ministry of energy and petroleum, 2015). Proportion in percentages of electricity generation is shown in the table 1 below.

Table 1: Electricity Generation Sources and Generated Energy

Sources of Electricity Power Generation		Installed Capacity Dec 2014		Annual Generation (2014/2015)	
		MW	Percentage	GWh	Percentage
Renewable Energy	Hydro	821	37.8	3466	36.8
	Geothermal	593.5	27.3	4060	43.1
	Wind	25	1.2	37	0.4
	Cogeneration	38	1.7	14	0.2
	Imports	-	-	79	0.8
	Totals	1477.5	68	7657	81.3
Fossil Fuels	MSD	579.5	26.7	1643	17.4
	Gas Turbines	60	2.8	4	0.0
	High Speed Diesel	25.8	1.2	36	0.4
	Emergency Plants	30	1.4	84	0.9
	Total	695.3	32.0	1767	18.7

Source: National Energy Policy 2015

Looking at the vision 2030 plans, Kenyan government plans to have a stable, competitive, cost effective, dependable and reasonably priced electricity supply from various sources to meet its objectives of accelerated growth in economy in all sectors ranging from manufacturing, service, mining and agriculture, the plan acknowledges the high costs of energy compared to her competitors thus it highlights the advancement in energy production and improved effectiveness in energy utilization in the country.

To meet the energy goals, a number of strategies including institutional reforms, encouraging of private power generations and the separation of generation from distribution for efficient operations have been put in place. Plans to secure newer sources of energy will ensure enough energy to meet the growing demand. This is done through exploration of renewable, nuclear, geothermal, coal, and intensified grid connection for transmission purposes.

1.2 The Kenyan Energy Market

1.2.1 Current Energy Sector Situation

The renewable sources utilized in Kenya are solar, small hydro sources, geothermal resources, biomass and wind. Of the total installed capacity, thermal plants accounts for 32%, both coal and gas turbines are currently not utilized extensively in Kenya for electricity generation but with the discovery of petroleum products and coal in the country, they are prospective to be utilized. Installed thermal capacity comes from medium speed diesel generators with total thermal installed capacity of 579.5MW, the gas turbines have a total installed capacity of 90MW located in Muhoroni, Western part of the country serving as emergency power plants, (Ministry of energy and petroleum, 2015). The thermal plants operate on imported petroleum products.

The country has experienced an upward growth in the electricity demand over the years attributed to the growth in economy. Between the year 2004 and 2014 the peak demand increased from 899MW to 1512MW at the same time the number of consumers trebled from 735 144 to 2757983 in the same period (Ministry of energy and petroleum, 2015). With a continuous growth of economy and increase in population, the peak demand is expected to grow to 5359MW by 2018. To meet this increasing demand additional new generations of 5000MW are to be developed by 2017.

As at 2014 the annual energy consumption was 8841GWh. This too is projected to increase to 32862GWh by 2017. The demand of electricity is majorly due to different projects coming up in the country such as LAPPSET, new cities coming up, iron and steel casting industries, new railway, and industrial parks. The table 2 below show the detailed trends in increase of consumers from the year 2004 to 2014:

Table 2: Demand of Electricity and Customer Data

Financial Year	Energy Generated GWh	Energy sold GWh	Peak Demand MW	Number of Consumers
2004/2005	5,347	4,379	899	735,144
2005/2006	5,697	4,580	920	802,249
2006/2007	6,169	5,065	987	924,329
2007/2008	6,385	5,322	1044	1,060,383
2008/2009	6,489	5,432	1072	1,267,198
2009/2010	6,692	5,624	1107	1,463,639
2010/2011	7,303	6,123	1194	1,753,348
2011/2012	7,670	6,341	1236	2,038,625
2012/2013	8,087	6,581	1354	2,330,962
2013/2014	8,840	7,244	1468	2,766,441

Source: KPLC Annual and Financial Report, 2014

1.2.2 Market power trends and development

The reliant on hydropower suffer a major setback in 1999 when the country faced a severe drought; this limited amount of generated electricity and in turn affected production sectors with agricultural and manufacturing sectors being heavily affected. In response, the ministry of energy with funding from World Bank came up with three emergency diesel fired power plants. To have reliable electricity source at all time, the government intentionally diversified Kenyan energy mix. The Ministry of Energy introduced Geothermal Development Company in 2008. The company's mandate was to fast tract development of geothermal potential (Geothermal development company, 2016).

The exploration of Kenyan Geothermal potential begun in 1957. Nevertheless, its exploitation for electricity began in 1981, today the country benefits from the 593MW installed capacity and plans to have an installed capacity of 5000MW from geothermal come 2030 (Matek, 2013). For base load, geothermal is preferable for the reason of being stable though its capital costs make it difficult to install.

Boosted by considerable investments amounts from national and foreign infrastructures, Kenya power sector experiences faster growth within East Africa. Several large projects are under construction which will increase energy security thus improving diversity in production. The projects in line include hydro plants, geothermal plants, wind power plants and coal plants. The road map undertaken by Kenya's Energy Ministry to realise the 5000+MW target within 40 months is shown below. August 2013 is taken as the base month (Republic of Kenya, 2015).

Table 3: 5000+ MW Project Implementation Timeline

Time in Months	6	12	18	24	30	36	40	TOTAL
Hydro	24	0	0	0	0	0	0	24
Thermal	87	163	0	0	0	0	0	250
Geothermal	90	176	190	50	205	150	785	1646
Wind	0	0	20	60	300	250	0	630
Coal	0	0	0	0	960	0	960	1920
Gas Turbines	0	0	0	700	350	0	0	1050
Co-generation	0	0	18	0	0	0	0	18
Total	201	339	228	810	1815	400	1745	
Accumulative additions	201	540	768	1578	3393	3793	5538	

Source: Republic of Kenya, 2015

It is not very clear how energy sector growth may meet the growing electricity country's demand in the country. The least cost power development plan assumes 14% annual growth rate in supply electricity between the year 2010 and 2030. The plan includes generation technologies like coal power and nuclear which are not in the current country energy mix, the plan inclines strongly towards geothermal as its favourite source for base loads and its capacity is projected to expand to 5530MW by 2030 (Ard, Harrison, & Elske, 2014).

Natural gas power and coal power electricity production technologies are also included in this plan. The evaluation and submission of proposals for the 700MW gas powered power plant in Dongo Kundu, Mombasa, is underway same as the 960MW coal fired power plant in Lamu.

Commissioning of Dongo Kundu gas plant is expected late 2016 while coal plant will be commissioned six months later (Ard, Harrison, & Elske, 2014).

Introduction of the nuclear electricity in Kenya energy mix was proposed by the National Economic and Social Council in 2010. The proposal came about because of the rising power demand brought about by the hastened growth in economy. The first nuclear plant is expected to deliver 1000MW and will be commissioned in 2024 while others are to follow later in 2026,2029 and 2031 summing up to 4000MW of installed capacity from nuclear (Ministry of energy and petroleum, 2015).

The expansion plan programme in the energy sector had proposed installed capacity of 5000+MW by 2020. By April 2015, 542.4MW under this programme were commissioned with the rest underway, 331MW were generated from geothermal, wind resources had an installed capacity of 20.4MW, while hydro and Medium speed diesel thermal plants both contributed 16MW and 80MW respectively (Ministry of energy and petroleum, 2015).

Electricity produced in Kenya is sold to Kenyan utility company, KPLC, for further distribution to the consumers. Transmission of and distribution of electricity is mandated to KPLC and KENTRACO. The transmission lines as at 2014 stood at 3,947km and 759.5km for KPLC and KENTRACO. Between June 2010 and June 2014 the annual percentage increase in the network was 6.54%. The distribution is done solely by Kenya Power and Lighting Company, as at the year 2014, the total distribution network was 52,850km (Republic of Kenya, 2015).

The government of Kenya has pledge to improve connectivity by expanding grid to connect Kenyans at affordable cost thereby initiating economic related activities in the country. This pledge, according to the government, would be achieved by extending the networks of low voltage to households within transformer distance of 600m radius. It also involves constructing line carrying low voltage along rural access roads.

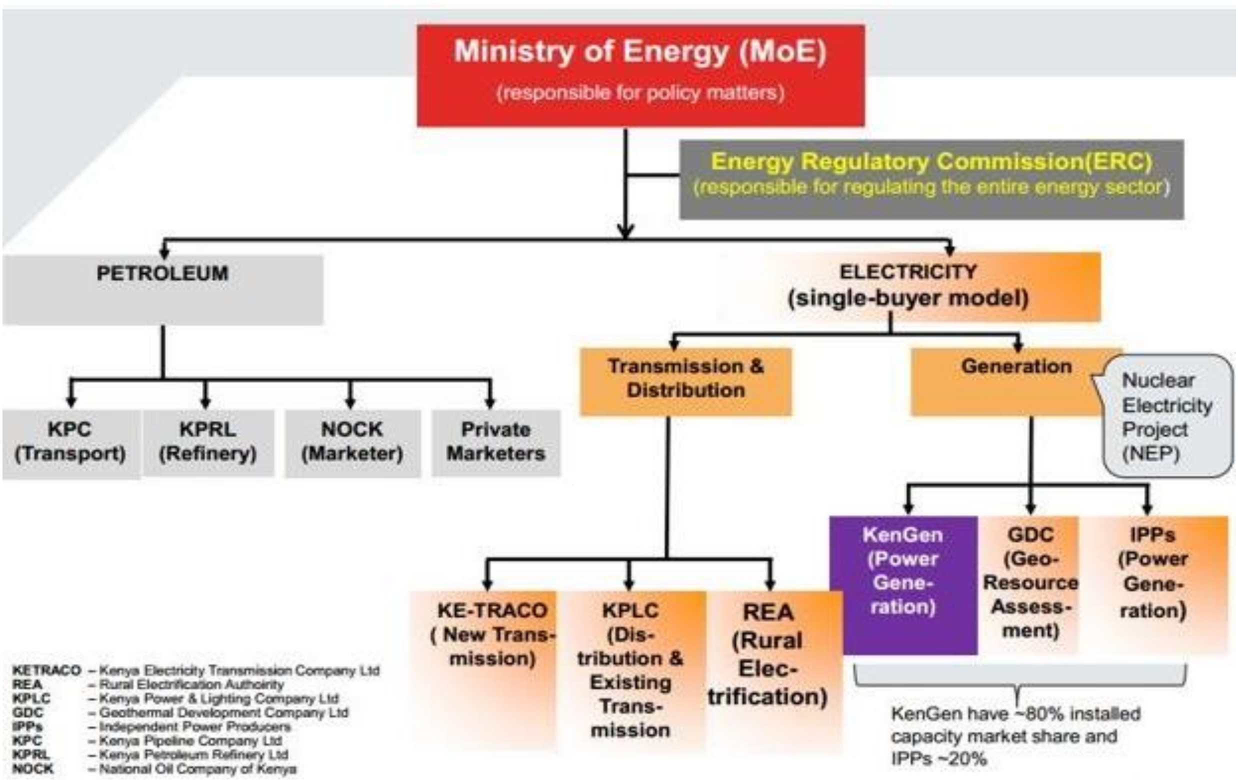
With favourable investment conditions, private investors in Kenya are able to secure funds from organizations such as World Bank and others given that government commitment to the expansion of energy and power sector is showing fruits. Nonetheless there still exist huddles in energy sector growth. Security environment concern in the Africa, lack of clear regulatory systems and corruption levels deter investors into financing energy projects.

1.2.3 Energy Sector Stakeholders

Ministry of Energy is the overall establishment and is mandated with providing leadership, guidance and implementation of energy policy and plans in Kenya. The two energy subsectors in Kenya are petroleum and electricity, also included is the geothermal energy, nonetheless other renewables are missing in the set up.

Kenya's electricity subsector is liberalized giving several players opportunity to get involved. It has three discrete categories; generation, transmission and distribution. Other institutions involve in the electricity sector include ERC, KPLC, Rural Electrification Authority, KENTRACO, Geothermal Development Company and lastly the IPPs as presented in figure 1.

Figure 1: Kenya's Energy Sector Chart



Source: KenGen

Each of these institution have specific duties. Table 4 shows the governments entities involved in Kenya’s energy sector formulating and executing policies with their specific roles (Republic of Kenya, 2015).

Table 4: Kenya Energy Sector

Affiliation	Institution	Role
	Ministry of Energy and Petroleum	Formulation of governing policies and implementation of sector planning
	The Energy Tribunal	Responsible for the settlement of disputes between energy regulatory commission and aggrieved stakeholder in the energy sector
	Energy Regulatory Commission	Regulates all energy subsectors and at the same time protects interests of stakeholders by ensuring reasonable on investments for their investments
	Rural Electrification Authority	Administer and manage rural electrification funds, implement programs related to electrification in rural areas through extension of national grid and off grid systems, recommendation of suitable policies and financing of projects feasibility studies for rural electrification.
	Kenya Electricity Generation Company (KENGEN)	It develops and manages all government owned electricity generation plants in Kenya.
	Kenya Power and Lighting Company (KPLC)	Transmit, distribute and sell electricity to customers in Kenya
	Kenya Electricity Transmission Company (KETRACO)	Plans, designs, constructs and maintains transmission lines and allied substations
	Geothermal Development Corporation (GDC)	Fast track development of geothermal resources in Kenya
	Kenya Pipeline Company (KPC)	Operate and maintain oil pipeline system and storage of petroleum products in Kenya
	National Oil Corporation of Kenya (NOCK)	Petroleum exploration and fuel marketing
	Kenya Petroleum Refineries Ltd (KPRL)	Crude oil refining in the country

With the liberation of the power sector, private investors started investing in power sector either into large scale generation of electricity or in the development of renewables utilizing the commendatory feed-in-tariffs policy. Collectively the independent power producers' account for 29% of the thermal installed capacity. The existing independent power plants are shown below. (Republic of Kenya, 2015).

Table 5 Independent Power Producers' in Kenya

Name	Install Capacity	Generation Type
OrPower	110MW	Geothermal
Iberafrica	108MW	Thermal
Tsavo	74MW	Thermal
Rabai	90MW	Thermal
Gulf	80MW	Diesel
Thika	87MW	Diesel
Mumias	26MW	Biomass Cogen
Imenti	300kW	Mimi hydro
Gikira	400kW	Mimi hydro

Source: Republic of Kenya, 2015

1.2.4 Energy Policies

The Energy act of 2006, led to the formation of ERC, a body tasked with issuing all licenses in the energy sector, devising and enforcing energy policies in the country. Although Kenya's energy sector is liberalized, ERC does not issue permits for private sector involvement in transmission and distributions for system larger than 1MW. Power plants to be connected to national grid are restricted to capacities greater than 500kW thereby locking up a number of small plants. To open up the electricity market, net metering, feed in tariffs and electricity banking policies should be developed and improved.

Feed in tariffs was introduced in 2009 by the government to provide an enabling atmosphere for financiers through strategy improvement. By the time of its creation, FiT policy only covered wind, biomass and small hydro for capacities of up to 50MW, 40MW, and 10MW respectively. In 2010 it was reviewed to accelerate endorsement of renewables comprising of solar, biogas and geothermal.

This policy was introduced to entice private investors into investing in the electricity production from renewable thus enhancing energy security, income generation and employment mainly for youths. The policy is set in a manner that it obliges the utility company to purchase energy generated from the renewable sources within a specific time.

New tariff set by the government targeted investors in geothermal which guaranteed a superior price of US8.5 cents/kWh while those of wind and biomass were reviewed upwards as follows from 9 US Cents and 7 US cents to 12 US cents and 8 US cents respectively (Kiplagat, Wang, & Li, Renewable energy in Kenya: Resource potential and status of exploitation, 2011).

1.3 Outline of this Thesis

The outline of this work is as illustrated. Chapter 2 sightsees relevant literature in two folds; it first looks at the link between consumption of energy and economic development, followed by the energy sources in Kenya looking at the potential of each source and cost associated with each. In chapter 3 research question and motivation is discussed. Methodology used to come up with different energy source potentials and LCoE costs are described in chapter 4, description of electricity production technologies as well as cost components is also included in this chapter. Chapter 5 presents the results obtained for both potential and LCoE for technologies considered. Discussion in chapter 6 delves on the benefits derived from continuous generation of electricity from geothermal heat and lastly chapter 7 concludes the thesis with recommendations on the economical source and imminent research suggestions.

2 LITERATURE REVIEW

Objectives of this thesis report is to identify sources of electricity in Kenya depending on how renewable the sources are and also comparing the cost of generation from each source. The motivation is to find and build upon a least cost energy source plan that will allow the country to grow socially and economically in line with the vision 2030.

The first task is examining the relation between energy use and economic development from existing literatures to validate the need of diversified energy mix in electricity generation to either match the growing economy or the help the economy grow depending on the link by meeting the growing demand. This will be followed by an inclusive literature review on energy sources in Kenya as well as discussing literature on the physical potential of each energy source. Finally, literature on electricity cost will be reviewed and gap to be filled will be identified.

2.1 Energy and Sustainable Development

Sustainability is defined as nonstop process of balancing ecological, social and economical dimensions, associated with the living environment and its systematic developments. Energy is an essential driver for sustainable economic development regarding its necessity for improving the social welfare. Therefore, its essential role in economic development, environmental impacts and the link between the two should be investigated to aid in policy making for a sufficient energy production and consumption.

There is a perceived link between energy consumption and economic growth. In a case where unidirectional interconnection exists and the direction is towards electricity consumption, the implication could be that energy policy implementation would have slight or no influence on growth of economy. However, if the causality exists in that the direction is towards economic growth, reduction in energy consumption would lead to a collapse in economic growth. At certain points when it is considered there exists no affiliation between the two, implying that whether the energy policies are applied, the economic growth will remain unchanged but maintain its own growth rate (Asafu, 2000).

There is a well-established relationship between economic development and the energy consumption but show a mixed for the directions of the interconnection.

Masih on her work on energy consumption, real income and temporal causality (Abul & Rumi, 1996), found out that the directions of interconnectivity between the two depend entirely on the level of economic development of country, for developing countries the study found a causal association while in developed countries there existed no such relationship. Kenya being a developing nation would therefore depict a causal relationship between economic growth and energy consumption.

It is argued that economic growth in many countries drive the energy consumption, growth in the economy of a country leads to an increase in electricity demand from different sectors of economy. This view is echoed by Mozumder & Marathe, (2007) in their study conducted in Bangladesh.

A study done in West Africa by Ouedragogo, (2013) established unidirectional connection between electricity consumption and the country GDP, the report indicates that the relationship obtained depended on time. It shows that in the short run GDP affected both the energy and electricity consumption and vice versa for the long run. It goes ahead to explain how the growth in GDP leads to increase in the consumption of both energy and electricity such as need to improve the comfort and increase in demand of energy in the production sector.

Findings by Azlina and Mustapha, (2012) establish the existence of long term connection amongst pollutant emissions, economic growth and energy consumption in Malaysia. The results from the study expose unidirectional causal relationship between energy consumption and economic growth and vice versa. Study done by Apergis and Payne, (2011) suggests that countries in the same development groups are capable of adopting same energy policies and strategies, the reason being the relationship between energy consumption and economic growth depends on the stage and level of a country's development.

However, some studies contrast the idea that countries in the same stage of development consume the same amount of energy hence the notion should not be generalized as the study done by Apergis and Payne suggest. Akinlo (2008) explored the relationship of Energy consumption and development in sub- Saharan Africa countries and deduced that same policies cannot be applied to their respective energy sectors but each country needs to come up with its own policies and strategies based on their needs at each particular time.

A number of studies on the issue have explored the relationship between electricity consumption and economic growth focusing only of electricity as a whole but not on the impact on the price of electricity. Affordability of electricity to consumers varies with price and availability of technologies used to produce electricity from different sources. If a consumer pays more for a unit of electricity, it becomes less affordable. According to Bildirici, et al., (2012) on the consumption of electricity and GDP growth in USA, whatever leads to the decreased in electricity consumption and use for example high and unaffordable electricity prices and unreliable electricity is capable of hindering both social and economic growth.

2.2 Energy in Kenya

2.2.1 Energy Source Potential in Kenya

A study done by Kiplagat, Wang and Li, (2011) provides in-depth information on the available renewable resources in the country, their existing potentials and their status of exploitation. They rank geothermal as the resources with a hugest potential standing at a range between 4000MW to 7000MW located along the Great Rift Valley. On biomass the trio point out that it is the largest form of primary energy consumed in the country nearly 74 % of the total national energy supply however, it is used in an inappropriate way leads to increase in deforestation.

A report done by the federation of universities of applied sciences shows that country Kenya has a high solar potential with a daily isolation of 4-6kWh/m^2. It further states that the utilization of solar energy has mainly been for photovoltaic systems, drying and water heating. According to the report the country only has 4MW as the installed capacity and approximately 140,000 installed water heating systems (Birgit, 2012). Kiplagat, Wang and Li, (2011) gives an average potential of solar to be 5kWh/m^2 and goes ahead to give its equivalent in tons of oil as 250 million (MTOe). Daniel (2008) reports that the maximum irradiance cannot exceed 1.356kW/m^2 indicating the country is exposed to high radiation levels.

In the existing literature, the wind potential is described using the available wind speeds. Kiplagat, Wang and Li, (2011) shows existence of great potential in some areas in the country such as Marsabit, Turkana, Ngong and coastal with high wind speeds ranging from 8 to 14m/s. The study further gives reasons such as complex topographical physical features including large inland lakes which influence both horizontal and vertical wind speed profiles and as a result making a number of locations to possess substantial wind energy potential. Daniel (2008) specifies that the country has plentiful wind resources with speeds of 2.8m/s and above considered low and utilized for water lifting appliances, the study also states that 90,000 square kilometres is available for excellent wind speeds in the country.

A lot has been done on the assessment of hydro potential in Kenya, Maher, Smith, and Williams, (2002) estimates the potential of pico hydro power to be at least 3MW and states that pico hydro has negligible environmental impact and with this potential pico can supply basic electricity to about 150,000 households. A review by Paish, (2002) indicates that small scale hydro operating on the basis or run of river is best due to cost and environmental issues. Kiplagat, Wang, and Li, (2011) classifies hydropower resources into large and small hydro they estimate large hydro potential to range from 3000 to 6000MW and further estimates that average potential energy production from large hydro to be at least 5935GWh per annum. The small hydro potential estimates according to the same study stands at 3000MW nationwide.

Little has been written on the fossil fuels in Kenya. To start with, Kenya's coal reserves are located in Mui Basin, divided into four blocks A, B, C and D. Block C has reserves amounting to four hundred million tonnes with a calorific value ranging from 16 to 27MJ/kg (Diakonia, 2014). Joan, et al., (2013) in their work reported a calorific value of 21.16MJ/Kg and further classified the composition of coal deposits in Kenya as follows: 33% anthracite, 20.3% bituminous, 11.4% lignite, 11.4% peat 3.8% carbonaceous shales and 20.1% was made up of rocks.

Talbot, et al., (2004) reported existence of good potential of petroleum in Lokichar Basin of the Northern Kenyan Rift mainly from algal-prone source rocks, according to the report, the section with the highest source lies within the Lokhone Shale Member with up to 17% of total organic carbon, report by Ecobank, (2014) indicates that Kenya is expected to start commercial oil extraction in 2017 with a production rate of 100,000 barrels per day mainly from Tullow oil company.

Majorly derived from forests, woodlands and bush lands, agricultural and industrial products, farm lands and plantations, biomass energy accounts for 74% of the total primary energy consumption in Kenya (Kiplagat, Wang, & Li, 2011). A study by Barnes, et al., (1994) explains that the use of biomass as a source of cooking energy is encouraged by the low income of rural dwellers and the ease of accessibility of biomass in Kenya.

Felix ter and Kai, (2007) carried out an assessment on the technical potential of domestic biogas systems and realized a 1.25 million households. The definition of the technical potential was based on the number of households that meet the basic requirements of adequate availability of dung, water and solid wastes. A feasibility study carried out on biofuel development in Kenya identified the potential and challenges facing the technology (Energy, 2008). The study also identifies the following crops as viable ethanol feedstock, sugarcane, cassava and sorghum while jatropha, cotton and sunflower as viable for biodiesel.

2.2.2 Cost of Electricity

For policy and energy planning purposes, valuing electricity is important for both social-economic, environmental issues and for the wellbeing of the general population. Bauknecht et al., (2012) cites that tariff determination based on LCoE is divided into three major steps:

- Definition of cost parameters
- Revenue Projection
- Transfer of LCoE into actual support levels

Cost parameter definition is differentiated into fixed and variable costs, fixed costs do not depend on the electricity output from the plant and are mainly investment costs and or fixed operational and maintenance costs whereas variable costs include costs that are dependent on the electricity output from the generating plant.

Not much study has been on electricity costs in Kenya. Tinnium, et al., (1994) describes reliability as the ability of power to meet customers' demand whereas maintaining the quantity, quality and electricity price at an acceptable level. Charlses M, (2005) explains the challenges faced by development of grid electricity in Sub Saharan Africa as lack of capital, poor coordination across stakeholder and high poverty levels amongst the population which results into inability to pay for the services rendered to them.

In promotion of energy access from renewable sources, execution of policies that addresses factors such as affordability, disposable income from consumers, availability and high quality of sources should be taken into consideration (Barnes, Williams, & Krutilla, 2005). Considering poor people and the vulnerable population living in rural areas, affordability is a great obstacle when it comes to electricity accessibility resulting to heavy dependency on traditional biomass to meet their energy demands.

In dealing with production costs from various energy sources, Morgan, et al., (2013) opine that policy and decision makers in developing countries have neglected the rapid decline in the costs of photo voltaic systems thereby still considering PV systems as not competitive to other technologies. Further the study cites the LCoE cost of solar PV ranged between USD 3.5-4/W_p in

2004 compared to USD 0.85-1.1/W_p in 2007. However, the LCoE of PV systems varies based on financial returns expected by the investors and the geographical location of the projects.

Lily, et al., (2009) showed that under normal geographical conditions, it less costly to extend the existing grid connection compared to off-grid alternatives. The report estimates connection cost of USD 1900 per household in rural areas, nonetheless lower cost connection fees are expected in dense urban areas and major cities of Kenya. The report also indicates the dissemination rate picked by the electricity planners play a vital role on household connection costs overweighing socio economic factors.

The available literature review in Kenya does not directly discuss the costs related to each generation technology and hence their inability to analyse the best energy source basing on the least cost analysis. This paper therefore seeks to fill the gap in the literature.

3 PROBLEM STATEMENT

3.1 Background Information

With the advancements of technology in the energy sector, there exist several technically available sources to meet the primary energy needs. The levels to which resources are utilized depend on factors such as cost, policies in place, amount of resource and technology availability resulting to an energy secure country for the ever growing demands, affordable energy for all while ensuring a lower carbon energy with respect to global warming.

Policymakers usually face challenges when developing energy frameworks. Necessity to improve accessibility of affordable energy to thousands living in the dark, environmental impacts driving transition to carbon free economy and the issues of investment and returns necessitate the assessment of different electricity generating technologies in Kenya. The main issue addressed in this write up is the problem of identifying the most suitable technology to develop in the country taking into account different parameters such as the LCoE costs, availability of resources and the benefits derived from the use of these resources in the production of electricity. This is not only an important step given that investors are willing to invest their capital in the best technology but also for government planning agencies who wish to shape their energy legislations for long term periods.

Costs comparison of electricity production from different sources and technology formulates the basis of decision making and development of new power plant investment plans. In this thesis competitive comparison for electricity generating alternatives is carried out. The task is to find the most economical source for additional generation of power taking into consideration the sustainability of the sources

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3.2 Research Question

The research questions is threefold. First, what are the energy sources potential for electricity generation in Kenya? Second, of sources identified, what are the most cost-effective sources? And finally, what are potential benefits of increased electricity production from geothermal heat?

To provide solution for these questions, I purpose to analyse the renewable energy potentials (solar, wind, geothermal, hydro and biomass sources) as well as fossil fuel (coal and oil) in Kenya. I will also perform per kilowatt hour cost analysis for the following sources of electricity: geothermal, coal, biomass cogeneration, wind, solar, wind, natural gas and nuclear.

4 METHODOLOGY

4.1 Energy Sources

Energy resource study was majorly done through review. Published information, archived data and internet resources were extensively reviewed for available data on different energy sources in Kenya. Among the reports that were referred to for biomass potential in Kenya include A Roadmap to Biofuels in Kenya; Opportunities and Obstacles, (MOE/GTZ 2008), Environmental Suitability and Agro-environmental Zoning of Kenya for Biofuel Production (Muok et al 2010) and Jatropha; A Reality Check (GTZ 2009). Semi organized discussions with stakeholders and key informers in the energy sector were conducted to get a deeper insight into the sector, as well as validate the data from the secondary sources.

For other energy source potentials, much of the data and information used was received from the Ministry of Energy, either from their library documents, or from papers presented at various forums. Where possible the accuracy of the information has been counterchecked by alternative sources such as international database.

4.2 LCoE Methodology

4.2.1 Introduction

Generation costs of electricity are crucial part of the energy market analysis and therefore a good understanding of these costs come in handy when analysing and designing policies related to the energy generation. Cost comparison from different energy sources associated to electricity generation is estimated using LCoE model.

Levelised cost of energy is the sum of all plant costs incurred during lifetime of the generating technology, divided by total quantity of electricity expected to be generated over the plant's lifetime expressed as dollars per kilowatt hour ($/kWh). Both are expressed in net present value terms (IEA/NEA/OECD, 2010). LCoE only relates to costs accrued to the owner of the generating plant, therefore it does not cover other costs that might in part fall to other stakeholders, such as network investments and air quality impacts.

Tariff determination based on LCoE is divided into three major steps:

- Definition of cost parameters
- Revenue Projection
- Transfer of LCoE into actual support levels

4.2.2 Electricity Generation Technologies Considered

Eight different electricity generating technologies have been considered in this research and whose technical and economic data are obtained from different sources ranging from government parastatals within the energy sector to the existing literatures on the Kenyan energy market. This section gives a relatively small description of the eight technologies covered in the LCoE calculations.

4.2.2.1 Ground Mounted Solar PV Technology

This technology uses semiconductors to convert sunlight to direct current electricity. Ground mounted solar PV systems are generally large in size. The solar PV arrays is made up of modules whose positions are held using frames. The frames are then mounted on the grounding support structure. The generated electricity can either be fed directly to the grid or stored in cells depending on the configuration of the power plant.

4.2.2.2 Small Hydro

Hydro plants rely on available water head to generate reasonable electricity. In a typical configuration, water from the reservoir is channelled to the turbine through penstock. Flowing water then exert pressure on the turbine blades causing a turbine coupled to a generator to rotate resulting to the generation of electricity. Reservoir acts as energy storage and usually comes handy with the changing load demands. Even with the existence of a dam, hydro plants' output is reliant on availability of water.

4.2.2.3 Geothermal

Generation of electricity from geothermal source is centred on the steam turbine attached to a generator. The steam power expanded in the turbine produces a rotary motion in the generator and as a result electricity is produced. Mostly used geothermal plant technology in Kenya is conventional flash system. In flashed steam power plant, the power plant uses reservoir water of temperatures greater than 182^{o}C. The fluid pressure decreases as the hot water flow to the surface and as a result some hot water flashes into steam. Steam produced is separated from water and then used in the power plant to generated electricity.

4.2.2.4 Onshore Wind

The wind farms in Kenya are to be situated Onshore thus the wind power LCoE calculations are based on onshore wind farms. Wind energy exploitation in Kenya is in favour of electricity generation with the main aim of substituting fossil fuels dependency in the country as well as the environmental issues.

4.2.2.5 Biomass Cogeneration

Combined heat and power systems are systems that concurrently produce heat in form of steam or hot water and power using one primary source. In Kenya the major source of cogeneration is bagasse from the sugar industries. Typical configuration of a cogeneration system comprises of an engine, steam turbine coupled with generator. A number of technologies can be applied to co-generate electricity and heat including steam turbines combined cycles, diesel engines and Gas turbines.

4.2.2.6 Coal Power

Coal fuel for coal power plants is ground and then burnt in a boiler to produce heat. The furnace heat in the boiler changes boiler water to steam, which rotates the turbines. Due to pollution from coal plants, it is imperative to come up with approaches for cleaner use of coal for electricity generation with reduced emissions. The development of clean coal technologies such as developing a more thermal efficient coal plant using less coal to generate equivalent amount of electricity.

4.2.2.7 Nuclear Power

Typical design of a nuclear power plant experiences the following processes, heat is created in the core located in the reactor vessel, and heat is carried to the steam generator using pressurised water in primary coolant loops. In the steam generator, water is vaporised into the secondary loop thus the production of steam, steam is directed to the main turbine for expansion.

The energy produced by splitting of U235 atoms are contained and its release is controlled by the nuclear reactors, heat energy is channelled to heat water thereby releasing steam which drives the turbine coupled with a generator hence produce electricity. Heat is obtained from fission of uranium as in the same way coal, gas or oil is used as sources of heat for fossil fuel thermal power plants.

4.2.2.8 Natural Gas Power Plant

Gas Turbine converts produced energy from combustion of fuel mixed with compressed air to drive a turbine to produce work. Natural gas plants consist of gas turbines coupled to an electric generator and heat recovery systems where exhaust gases are fed for heat recovery. The dominant technology used is the combined cycle gas power plant for base load electricity generation.

4.2.3 Cost Components

Cost parameter definition is differentiated into fixed costs and variable costs, fixed costs do not depend on electricity output from the plant and are mainly investment costs and or fixed operational and maintenance costs whereas variable costs include costs that are dependent on the electricity output from the generating plant. Various components of Capex and Opex costs are summarised in table 6.

Table 6: Cost components for the LCoE model

Cost Components	Definition	Definition/ Interpretation
Capex Costs	Construction Costs	➢ Pre-development costs ➢ Construction costs ➢ Infrastructure costs
Opex Costs	O & M costs	➢ Fixed Opex ➢ Variable Opex ➢ Insurance ➢ Connection costs ➢ Carbon transport and storage costs ➢ Heat revenues ➢ Fuel Prices ➢ Carbon costs
Other Input for the model	➢ Plant capacity factor ➢ Expected plant efficiency ➢ Expected plant availability ➢ Plant load factor	

Source: DECC, 2013

4.2.4 Cost Components Description

4.2.4.1 Investment Costs

These are capital costs incurred in building and installation of electricity generating power plant and is taken as per kilowatt of the installed capacity. Investment costs can either be direct or indirect relating to installing and commissioning of a power plant, it also comprises of costs incurred before or during plant construction phase. Investments costs do not include cost of land and predevelopment costs such as administration and approval costs.

4.2.4.2 Discount Rates

LCoE calculation for different electricity generation technologies in Kenya is done using two discount rates, 10% discount rate is used for base cases and 12% has been used for sensitivity analysis.

4.2.4.3 Plant Lifetime

An average lifetime of each electricity generating technology was taken as follows; coal power plants having a life span of 40 years. Natural gas fired plant having a lifetime of 20 years, 40 years for nuclear power plant, wind power and biomass cogeneration both having 20 years, 25 years lifetime for geothermal power plant and solar photovoltaics with and lastly hydro plant with a lifespan of 50 years.

4.2.4.4 Operation & Maintenance Costs

Plant operation and maintenance costs usually vary between different forms of electricity generation and its value plays a major role in plant costs analysis. These include labour costs, assets and site managements, costs for safety and maintaining heath, and general maintenance of the plant and are usually not linked to plant initial costs. Variable costs considered include consumption of auxiliary materials such as water and fuel additives, spares parts, treatments and residual disposals. However, insurance and guarantees costs are not considered.

4.2.4.5 Fuel Costs

This cost is not considered for all sources of electricity discussed in the paper as most renewable technologies do not require fuel hence no need for these costs. Technologies that do not require fuel for their operation include geothermal, wind, solar and hydro as the resources associated with them are available freely and this forms one of their main advantages over other technologies. Fuel costs is only considered for nuclear plants, natural gas power plant and coal power plant and the projected fuel costs are according to IEA world energy outlook 2015.

4.2.4.6 System Costs

This include balancing costs, profile costs and grid costs. Balancing costs are associated with handling deviations from planned production costs. Profile costs are comparison of the value of electricity generation by a technology to a standard value such as average market electricity price. The grid costs are costs incurred in expansion and adjustments of grid infrastructure.

4.2.4.7 Full Load Hours

To express the utilization rate of the plant under consideration, annual full load hours is used. Full load utilization has a high influence on the LCoE calculations since it affects directly both fixed costs and fixed operational and maintenance costs. For the renewable sources such as wind and solar having low marginal costs, their annual utilization rates are dependent on available resources and the choice of technology employed. For the thermal plants their full load hours majorly depend on their mode of operation whether operating as base load, mid load or as emergency power plants.

4.2.5 LCoE Model

In this section, LCoE model methodology is described, technologies employed in electricity generation discussed in this work are defined by their investment costs, operational and maintenance costs both fixed and variable, energy efficiencies, plant lifetime, plant construction time and the emission factors for the fossil fuel powered plants.

The LCoE method of analysis is taken as the basis of comparing available options for investments into the power plants and it reflects the minimum price at which generated electricity has to be sold for the investment to pay off within the range of plant lifetime. Various components used in the LCoE evaluations are obtained using the different formulas.

4.2.5.1 Capital Costs (C_p)

The capital costs are transferred to dollar per kilowatt hour using capital recovery factor (R), capacity factor (f) and hours the plant operate per annum (H).

$$\text{Capital Cost} = \left\{\frac{C_p * R}{H * f}\right\}$$

Recovery factor is a share of costs of power plant that revenue must cover annually to recover all the capital costs over the plant operating life. The amount of capital that should be recuperated per year is essential for the calculation of LCoE. This amount is calculated using both the discount rate (r) used and plant life expectancy (T).

$$R = \frac{r * (1 + r)^T}{(1 + r)^T - 1}$$

Plant capacity factor is defined as the power produced annually divided by power produced by plant when it's running at 100 per cent over the period of same year. To obtain the total number of hours electricity is produced by a plant annually, the capacity factor is multiplied by hours the plant runs within a given year. Per kilowatt hour cost is then evaluated by dividing the annual cost by plant operational hours (H*f)

4.2.5.2 Operation and Maintenance (C_o)

For calculation of the operation and maintenance costs, the capacity factor and the number of hours the plant run is used together with the levelization factor (l). To transform annual costs into dollar per kWh, the capacity factor and hours the plant runs per year is used. The levelization factor takes into account the increase as the plant ages and it is depended on discount rates (r) and the annual escalation cost rates for the project in question.

$$\text{O \& M Costs} = \left[l * \frac{C_o}{H * f}\right]$$

Where $$l = \frac{r*(1*r)^T}{(1+r)^T-1} * \frac{(1+e)}{1-e} * \left(1 - \left(\frac{1+e^T}{1+r}\right)\right)$$

4.2.5.3 Fuel Costs (C_f)

This cost is not considered for all sources of electricity discussed in this thesis as most renewable technologies do not require fuel. The long term changes expected in prices of fuel are capable of reversing the overall plant cost and as such affecting the plants profitability. To account for the increment in the fuel cost due to inflation, per kWh cost of fuel is multiplied by the levelization factor.

$$\text{Fuel Cost} = \left[l * \left(\frac{C_f}{H * f}\right)\right]$$

Finally, the total cost is the summation of the capital cost, operation and maintenance costs and fuel costs. From the equations shown above, the general LCoE formula therefore is as below.

$$\text{LCOE}_{\text{estimate}} = \frac{\text{NPV of Total Costs}}{\text{NPV of Electricity y Generation}}$$

Where

$$\text{NPV of Total costs} = \sum_{n} \frac{\text{Total capex and opex costs}_n}{(1 + \text{discount rate})^n}$$

$$\text{NPV of Electricity yGeneration} = \sum_{n} \frac{\text{net electricity ygeneration}}{(1 + \text{discount rate})^n}$$

$$\text{n} - \text{time period}$$

Advantages of using the LCoE methodology to evaluate energy generating technologies are that all fixed costs incurred during the plant generation period are combined in a single value serving as proxy. It also allows for cross power generation technology comparison. With this method, conventional plants can easily be compared to renewable sources such as solar, geothermal and wind power generating technologies although the technologies have different construction cost structures and construction time.

4.2.6 Limitations of LCoE Method

LCoE usually provides the simplest way of comparing technology choices in terms of costs. However, this method is associated with a number of limitations. To start with it mainly deals with base load technology, electric power generation technologies for high number of full load hours considered constant over the plant life span. Also considered fixed over the plant lifetime is the rate and price of co-generated heat.

Moreover, this method only considers the direct costs incurred and not the revenue generated from the technologies, the costs incurred are considered to be evenly distributed over the entire plant lifetime as opposed to the cash flow method, and hence the method cannot be used to establish the rate of return of the project. The costs considered are capital construction costs, operations and maintenance costs and fuel costs.

The final limitation of LCoE model is the sensitivity to the discount rate. Usually it is very difficult to find accurately the true discount rates at the time of investments since it may change over time. This report will try to mitigate this limitation by using sensitivity analysis by considering both high and low cost scenarios taking 10% and 12% discount rates cost scenarios respectively. The scenarios will show the impacts created by the discount rates on plant LCoE costs.

Limitations of the report are mainly due to data availability for both economic calculations and the sources potential analysis. For LCoE calculations, standard costs were used for capital costs. Operational and maintenance cost, heat values and for capacity factors. The costs values were arrived at by taking average costs associated with electricity generation for a number of power plants for each technology considered. Given that Kenya imports fuel, the fuel costs were taken from International Energy Agencies World Energy Outlook 2015 for coal, nuclear and natural gas. Lack of this specific electricity generating costs in Kenya for the different sources limits the accuracy of result analysis.

5 RESULTS

This report uses the sources potential and generation costs to identify the most abundant resource and the most economical source for electricity generation in Kenya. This part presents the findings of the analysis carried out on the costs electricity generation from different sources as well as resources analysis. Following will be a discussion on the benefits derived from electricity generation from geothermal source.

5.1 Energy Resources in Kenya

Major aim of the energy policy and policy makers is to warrant cost effective, quality, adequate and affordable supply of electricity to meet the country's development needs without compromising on the environment solely by utilization of the available energy resources. Kenya is endorsed with a number of natural occurring energy resources that can be harnessed to generate electricity; these resources include Hydro, Geothermal, Solar, Wind, Biomass cogeneration, coal, lastly Oil and Gas.

5.1.1 Geothermal Resources

The development of geothermal resources exploration and exploitation in Kenya date back to 1950, currently installed electricity generating capacity from geothermal is 573MW. Kenya has high temperature prospects geothermal fields which are located within its Rift Valley. Largest geothermal field in Kenya is located in Olkaria. In this field KenGen operates an installed capacity of 463MWe and additional 110MWe comes from Orpower4 an independent power producer. Six other wells have been drilled in Eburru and 25 wells in Menegai area.

High temperature occurrences in Kenya's geothermal fields are majorly associated with Quaternary volcanoes along the axis of the Great Rift Valley. Shallow magma bodies under the volcanoes are the main heat sources in these systems. Kenya has 14 large Quaternary volcanoes and together with other potential sites, a total of 10,000MWe geothermal potential is estimated in the Country (Peter, 2014). The government of Kenya has fast tracked development of geothermal generation by initiating well drilling in both Menegai and Olkaria fields. Kenya's electricity generating installed capacity from geothermal from 1985 to 2014 is shown in table 7.

Table 7 Geothermal Generation Installed Capacity

Location	Power Plant Name	Year Commission	No. of Units	Unit Type	Installed Capacity
Olkaria	Olkaria 1	1985	3	Flash	45
Olkaria	Olkaria 2	2003	3	Flash	70
Olkaria	Olkaria 2 Unit 3	2010	3	Flash	35
Eburru	Eburru	2010	1	Binary	2.5
Oserian	Oserian	2003, 2006	2	Binary	4
Olkaria	Olkaria Wellhead OW37	2013	1	Flash	5
Olkaria	Olkaria Wellhead OW43	2014	4	Flash	12.8
Olkaria	OrPower 4-Unit 1	2000		Binary	52.8
Olkaria	OrPower 4-Unit 2	2008		Binary	39.6
Olkaria	OrPower 4-Unit 3	2014	1	Binary	17.6
Olkaria	Olkaria 4 Unit 1	2014	1	Flash	70
Olkaria	Olkaria 4 Unit 2	2014	1	Flash	70
Olkaria	Olkaria 1 Unit 4	2014	1	Flash	70
Olkaria	Olkaria Wellhead	2014	1	Flash	32.8
Olkaria	Olkaria Wellhead	2014	1	Flash	30
Olkaria	Olkaria 1- Unit 5	2014	1	Flash	70
Total					573

Source: KenGen

5.1.1.1 Olkaria Geothermal Field

This field lies on the axis of the Great Rift Valley, towards the Mau escapement which is dominated by rhyolite flows and pyroclastics rocks, also present in the Olkaria landscape are volcanic sites. Olkaria fault systems are dominantly in NW-SE, N-S and NE-SW directions. The last two are the youngest while NW faults are older and associated with rift graben formation. These types of faults are common where field merges into the Pliocene Mau escarpment mainly to the west. The Great Olkaria field is divided into seven fields; East, West, North-West, North-East, Central, South-East and the Dome having a capacity to generate more than 1500MWe (Omenda & Silas, 2015).

Olkaria 1 field is located in the eastern part of Olkaria Field and is home to the first ever geothermal plant in Kenya, Olkaria 1 power plant. The first well under the funding of UNDP was drilled in 1973 in this location and a plant with an installed capacity of 15MWe was commissioned here in

1981. 2014 show the expansion of Olkaria 1 field to 140MWe. Steam production in this field was further increased by drilling wells deeper to a depth of 3,000m. The previous wells had depths between 900m to 2200m.

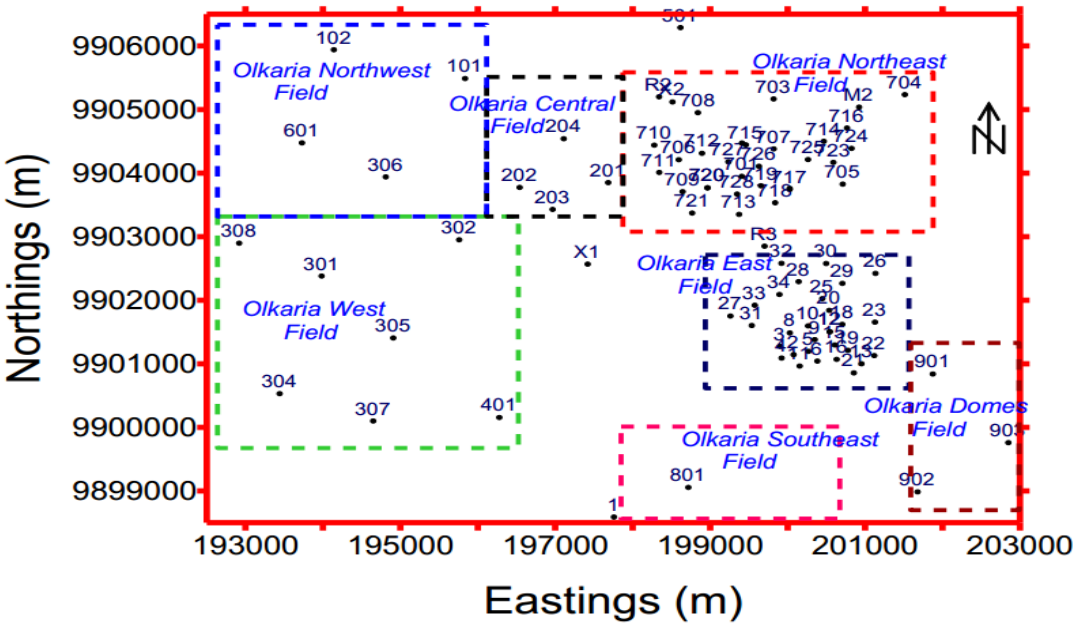
Located in the North Eastern part of the Olkaria field is the Olkaria 2, Olkaria 2 is a home to a 70MWe plant with two units each with an installed capacity of 35MWe. This plant was commissioned in 2003. In 2010 additional 35MWe unit was commissioned. Currently the installed capacity of this field is 105MWe; there is on-going drilling with the main aim to increase the capacity of the field.

Located in the west of the Olkaria field and hosting Olkaria 3 power plant operating on an organic rankine cycle is the Olkaria 3 geothermal field, this plant is the first ever private operated power plant in Kenya. Development in this field was done in phases starting with an 8MWe commissioned in 2000 and currently the power plant has been expanded to 110MWe.

Olkaria 4 geothermal field has an approved capacity of 350MWe. This is from the surface exploration done in 1993 followed by closely by drilling of the three exploration wells in 1999. Olkaria 4 power plant with an installed capacity of 140MWe from two units of each 70MWe was commissioned in 2014. Further appraisal and production drilling is currently being carried out in the eastern sector with an aim to host additional 140MWe for the Olkaria 6 power plant.

Olkaria central field is characterised by lower outputs as result of lower reservoir temperatures and lower permeability. This field is located between NE and West fields. Plants in this field majorly run on Organic Rankine Cycle. A 2MWe plant in this field is run by Oserian Development Company which uses wells leased to them from KenGen. Apart from electricity generation, the company utilizes the source for direct use purposes mainly for heating their green houses.

Figure 2: Olkaria Geothermal Field



Source: KenGen

5.1.1.2 Eburru Geothermal Field

This field is located to the North of Olkaria. After completion of detailed surface study in 1990, six exploration wells were drilled between 1989 and 1991. One of six drilled wells encountered temperatures greater than 250°C (Onacho, 1990). Even though the MT/TEM survey conducted in 2006 that revealed the capability of Eburru field of supporting up to 60MWe only a 2.5MWe condensing plant was commissioned in 2012 (Peter, 2014).

5.1.1.3 Menengai geothermal field

This field is located in the axis of the central Kenyan Rift segment. Menengai being a major Quaternary caldera volcano is located in an area categorized by complex tectonic activity characterised by two tectono-volcanic axes in Molo town and Solai. The Menengai potential area is mapped as 84Km^2 translating to more than 1650MWe (Peter, 2014). The rock structures in this field are similar with the ones in Olkaria field therefore corresponding permeability is assumed.

Exploration drilling in Menengai started in 2011, today a total of 25 deep wells up to a depth of 3200m have been sunk. At depth of 2000m reservoir temperatures of up to 400°C have been encountered in a number of wells hence making it the hottest reservoir in Kenya. Steam production from the wells varies from small to greater than 12MWe and a total of 80MWe is under well heads generation in this field. There is a planned full steam production for a 105MWe power plant (Peter, 2014).

5.1.1.4 Suswa Geothermal Fields

This forms the outermost series of the Quaternary caldera in the Kenyan Rift. The volcano has two calderas, the outer and inner diameters of 10 and 4 Km respectively; the volcanic products associated with the volcano include trachytes and phonolites. Detailed results obtained from the surface study at Suswa suggest reservoir temperatures of greater than 300^{o}C. Further studies done using seismic and gravity method indicate that heat source under the caldera is about 6Km deep. The geothermal potential of this field is postulated to be about 100MWe (Omenda, et al., 2000). Drilling exploitation on this area commenced in the year 2015 by GDC in conjunction with the private partners.

5.1.1.5 Longonot Prospect

Longonot forms the largest caldera volcano in the floor of Southern Kenya Rift. The caldera is composed of trachyte caldera about 11 km diameter. In this area geothermal appearance is in the form of fumaroles and hot grounds. The study done in this area indicated a prospect area of 60km^2 and that study was followed by siting of three exploration wells. The estimated power output from this geothermal field is 200MWe (KenGen, 1998).

5.1.1.6 Baringo Prospects

Baringo geothermal field is sited in the North Rift next to Lake Baringo. Geothermal surface manifestation is in the form of hot springs, fumaroles, irregular ground water bore holes and lastly thermally altered hot grounds while the geology is characterised mainly by trachyte and trachyphonolites. Reservoir temperatures recorded on the western part of the field ranges from 120-200^{o}C (Peter, 2014).

5.1.1.7 Korosi Prospects

This field is located in the Northern Rift bordering Lake Baringo to the South and Paka volcano to the North. Detailed studies performed in this field between 2005 and 2012 indicated geothermal surface manifestations in the form of hot grounds and fumaroles and a surface temperatures ranging between 90 to 95^{o}C. Using H_2S Gas geothermemetry, five samples from Korosi indicated temperatures of higher than 250^{o}C under the reservoir (Peter, 2014).

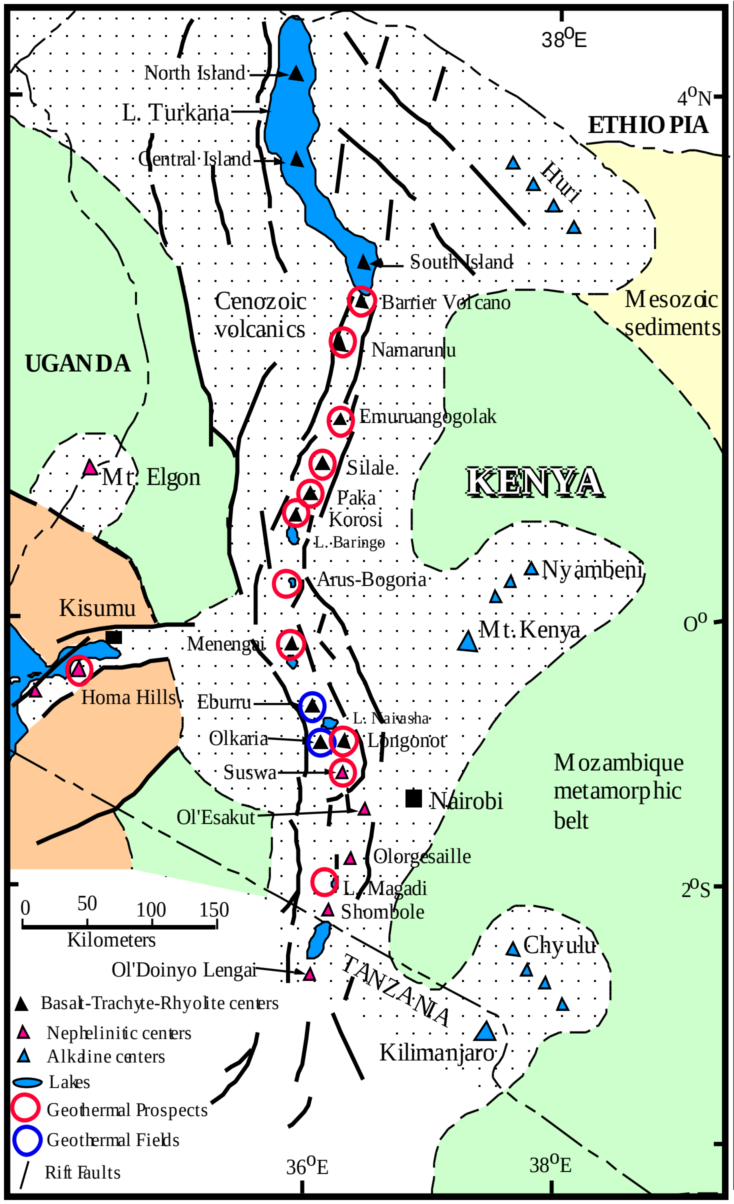
5.1.1.8 Paka Prospects

Detailed geothermal surface studies to establish the potential of this field started in 2006 to 2007. Geothermal manifestation in this region is in form of fumarolic activities, hot grounds and thermally altered rocks. The reservoir temperatures according to gas geothermometry are higher than 250^{o}C. Paka Geothermal field estimated potential is greater than 500MWe (Geoffrey, 2010).

5.1.1.9 Other Geothermal prospects

There are a number of geothermal fields whose potential has not been examined into details. However, plans have been put in place by GDC for a period of three years and are expected to be finished in 2017. These fields scheduled for studies include Lake Magadi, Emuruangogolak, Namarunu and Barrier volcanic complex. Lake Bogoria and Arus fields also have potential to generate enough steam for electricity generation (Karingithi & Wambugu, 2009). Shown in figure 3 are the locations of different geothermal fields along the Kenyan Great Rift Valley.

Figure 3: Geothermal sites in Kenya and their potentials



Rift Region	Estimated Potential (MW)
Central Rift	
• Menengai	1,600MW
• Eburru	250MW
• Arus Bogoria	400MW
	2,250MW
South Rift	
• Olkaria	2,000MW
• Longonot	750MW
• Suswa	600MW
• Lake Magadi	100MW
	3,450MW
North Rift	
• Lake Baringo	200MW
• Korosi	450MW
• Paka	500MW
• Silali	1,200MW
• Emuruangogolak	650MW
• Namarunu	400MW
• Barrier	450MW
	3,850MW
Nyanza	
Homa hills	100MW
Akira	350MW
	450MW
Total Estimated Potential	**10,000MW**

Source: KenGen

Geothermal potential in Kenya is estimated to be 10,000 MW located in different fields within the Great Rift Valley, of which less than 600 MW have been developed in Olkaria to generate electricity, leaving an enormous untapped potential suitable for base load electricity generation.

5.1.2 Solar Resources

Kenya has massive solar resource potential. However, the actual quantity of solar energy potential received is somehow low; reasons being time variations, the quantity of the solar energy source received at a given location is subject to daily and seasonal variations, secondly the geographical variation also affects the amount of solar energy received; Kenya being along equator receives supplementary solar energy compared to sub Polar Regions. Other factors affecting quantity of solar energy reaching the earth surface include weather conditions and siting options.

Kenya receives high irradiance ranging from 4 to 6kWh/m^2/day; hotspots in the northern and north eastern parts of country have the higher insulation rate with an average of 5 peak sun hours. The amount of energy received per year in Kenya depends on the location and ranges between 700 kWh in the mountainous areas and 2650 kWh in arid and semi-arid areas. Most of the regions in Kenya experiences between 1750 to 1900 kWh of solar energy (SWERA, 2008). Nonetheless only small portion of this enormous resource has been harnessed

Application of solar energy in Kenya include both solar thermal for heating and drying, and solar PV mainly used for lighting, pumping and for off-grid telecommunication boosters.

5.1.2.1 Status of solar energy in Kenya

Positive observations have been seen in Kenya following the introduction of rural electrification programme, there has been an average growth of 20,000 solar home system installations and the Ministry of Energy projects the demand of the same to reach 22GWh in the year 2020. Most of these installations are in education and health institutions located in arid and semi-arid areas where the national grid extension is very poor.

The solar market infiltration is expected to improve tremendously through government support. Given that a higher percentage of the Kenyan population live in the rural, there exist a huge market for tapping the enormous solar potential for solar home systems to be harnessed for water heating, electricity generation for pumping, lighting, powering television sets and lastly for telecommunications facilities in remote locations.

The entire surface area of Kenya receives utilizable amount of irradiance and it has majorly been used for home drying of cereals. However, different locations receive different irradiance depending on the closeness to the equator, mountainous features and the forest cover. Table 8 shows class distribution of irradiance per kW/m^2 received in Kenya and the total area coverage in km^2.

Table 8: Analysis of Normal Irradiation Solar Energy Available in Kenya

DNI ($kW/m^2/day$)	Area (KM^2)	DNI ($kW/m^2/day$)	Area (KM^2)
3.5-3.75	41 721	5.5-5.75	33 848
3.75-4	61 515	5.75-6	20 211
4-4.25	140 326	6-6.25	24 675
4.25-4.5	177 347	6.25-6.5	33 690
4.5-4.75	137 572	6.5-6.75	22 468
4.75-5	96 199	6.75-7	16 240
5-5.25	62 364	7-7.25	6 736
5.25-5.5	48 826	7.25-7.5	2 256

Source: SWERA

The direct normal irradiation of $6.0kW/m^2$ and above can and will be utilized for heat generation in households, institutions and industries within the country. From the table above a total of $106,000km^2$ has the capacity to deliver $6.0kW/m^2/day$. This capacity translates to a potential of 638,790TWh of energy awaiting exploitation.

5.1.3 Hydro Resources

Technology used to harness the electricity from the hydro potential relies on the available head in the rivers to drive the turbine. Typically, water is fed from reservoir through penstock to the turbine house. Pressure exerted on the turbine blades by the flowing water causes the shaft connected to the generator to rotate hence generating electricity. Basing on this technology, the potential to harness electricity and mechanical power from rivers in Kenya is enormous, Kenya's hydro potential is considered enormous for the reason of its geographical features and presence of perennial rivers distributed all over the country.

The estimated hydropower potential in Kenya is about 6000MW consisting of large hydro for power plant whose installed capacity is more than 10MW and small hydro. Small hydro potential amount to over 3000MW out of which merely 20MW has been exploited. As at 2013, 807MW had been exploited translating nearly 50% of the total installed capacity at that time. The economic potential from the unexploited hydro in Kenya is 1449MW and can be utilized for hydro projects larger than 30MW.

The 6000MW potential translates to an annual energy consumption of not less than 5605GWh, the locations of these potential is distributed across the country within the five geographical regions of Kenya's main drainage basins, Tana river basin has the highest potential and has a number of power plants situated along it. Major drainage basin in Kenya with their corresponding potentials is presented in table 9.

Table 9: Drainage Basins in Kenya and Their Potentials

Drainage basin	Potential in MW
Tana River	800
Rift Valley	345
Ewaso Ngiro North	146
Lake Victoria	295
Athi River	84

5.1.3.1 Small Hydro Potential

Harnessing energy from small hydropower plant in Kenya started over a century ago primarily for grinding food grains. Coming up of tea factories and the work of missionaries resulted to introduction of turbines to generate electricity. To date several small hydro power plants are run by communities and private entrepreneurs in the country. The government ventured in the small hydro power plant generation partially due to inadequate grid connection and the need to power remote areas isolated from the national grid.

Categorized as small, mini and micro hydropower, the small hydro potential nationwide is estimated as 3000MW, coming from approximately 55 river sites whose capacity range between

50-700kW (Kiplagat, Wang, & Li, Renewable energy in Kenya: Resource potential and status exploration, 2011). These sites are located in rural areas with poor grid extension and at times not available therefore suitable for stand-alone systems supplying electricity to small isolated communities.

Lake Victoria basin account for nearly 45% of the identified small hydro potential, other promising sites are located in Tana River basin mainly in Thika, Meru South, Meru Central and Maragua districts. Development of small hydro in these potential sites is hindered by inaccessibility and some sites are also deemed not economically viable for grid integration. However, with the introduction of favourable feed-in tariff for small hydro, there has been a major shift and several small hydro projects are under development in the country.

Further these small hydro plants require slight or zero water storage at all. They operate on a run of river system kind of power plant system and only require a small pondage for silt settlement purposes. However, lack of storage system and the unreliability of the rainy seasons, these plants become subject to seasonal river flows and as a result they operate as intermittent energy sources.

5.1.3.2 Existing Hydro Projects in Kenya

Kenya categorises stations that have installed capacities more than 20MW as large hydro. Currently Kenya has nine large hydro power plants with a total installed capacity of 806.2MW, these plants include Tana, Masinga, Kiambere, Gitaru, Kamburu, Turkwel, Sondu Miriu, Sangoro and Kindaruma.

Small hydro in Kenya refers to those plants whose installed capacities are less than 20MW. They can either be connected to the grid or be constructed in isolated areas considered uneconomical to extend the national grid or areas lacking grid connection to enhance rural electrification. There exist a number of small hydro power plants in Kenya and their contribution to the total installed capacity amount to 31MW. Of the existing small hydro power plants, the range of installed capacity is between 0.017MW to 2MW (Ministry of Energy and Petroleum, 2014). Large hydro installed capacity from different rivers in Kenya is shown in table 10.

Table 10: Existing Large Hydro Projects in Kenya

Power station	River	No. of Unit	Installed Capacity (MW)
Gitaru	Tana	3	225
Kiambere	Tana	2	168
Turkwel	Turkwel	2	106
Kamburu	Tana	3	94.2
Kindaruma	Tana	3	72
Sondu	Sondu	2	60
Masinga	Tana	2	40
Sangoro	Sondu	2	21
Tana	Tana	4	20
Total		23	806.2

Source KenGen 2014

5.1.3.3 Planned Hydro Power Plants

In Kenya hydro resource potential is currently under developed. Development of new hydro power plants and optimization of the existing plant has been initiated by the government with the aim of meeting its least cost development plan. In line with this plan, a number of prospective large hydro resources in Kenya are being considered; these prospects include the Grand Falls whose potential ranges from 500 to 700MW, Arrow 60MW, Magwagwa 120MW, Nandi Forest 50MW and Karura 90MW.

Most promising sites are Karura and Grand falls which are considered favourable for immediate developments. Remaining locations are not considered candidate sites since they still require further feasibility studies. The case of Ewaso Nyiro South whose potential is 220MW experiences environmental issues resulting from the cross boundary issues that need to be resolved before embarking on its development.

5.1.4 Wind Resource Potential

Wind monitoring programme initiated by the Ministry of Energy in Kenya, provided bankable wind resource data, this programme resulted into installing wind masks with data loggers at the heights of 40m and 20 metres high. Wind masks are located in 95 sites countrywide and records wind speeds parameters used for pre-feasibility studies of wind resources in Kenya for large scale development of wind farm.

Kenyan government in 2008 initiated a research study under Energy Sector Recovery Project for 'Wind Energy Data analysis and development programme'. This research revealed that 73% of the total surface of the country experiences annual wind speeds more than 6m/s at heights of 100m above ground. This fact indicates the huge potential for the utilization of wind sources for electricity generation rather than for water pumping as it has been used before. Wind regimes in Kenya are capable of large scale generation of electricity. Some of these regimes experiences annual wind speeds ranging from 6-10m/s throughout the year, areas enjoying high speeds are Marsabit, Ngong and the Coastal region. Looking at Africa's wind potential, Kenya's potential is ranked as one of the highest with a total of 346W/m^2. Regions in Kenya considered to have best wind include Marsabit districts, Samburu, Meru North, Nyeri, Nyandarua Ngong Hills and some parts of Laikipia districts.

The estimated wind potential in Kenya is classified into classes, class I has wind speeds greater than 8.5m/s, class 2 has wind speed range between 7.5m/s to 8.5m/s, class 3 wind speed ranges between 6.5m/s to 7.5m/s, class 4 ranges from 5.5 to 6.5m/s as shown in table 11.

Table 11 Wind Classification in Kenya

Kenya wind classes				
Class No	Classification	Wind speed (m/s)	Wind power density (W/m)	Colour code
6	Poor	0-4.5	0-90	
5	Marginal	4.5-5.5	90-165	
4	Moderate	5.5-6.5	165-275	
3	Good	6.5-7.5	275-425	
2	Very Good	7.5-8.5	425-615	
1	Excellent	≥8.5	≥615	

Source: SWERA

Wind power densities are generated using wind speeds. For wind investment purposes other parameters such as availability of grid and supply of the reactive power are considered a necessity for large scale wind farm projects. The table 12 below gives details of wind densities per square kilometres in the country.

Table 12: Wind Classes per Square Kilometres

Wind Speed Classes	Area (KM^2)	Wind Speed Classes	Area (KM^2)
2.8	65,034	6.8	11,113
3.2	29,412	7.2	6,955
3.6	33,567	7.6	6050
4.0	37,870	8.0	4,026
4.4	76,079	8.4	2,417
4.8	141,159	8.8	1,149
5.2	83,269	9.2	460
5.6	44,269	9.6	409
6.0	29,990	10.0	153
6.4	27,137	10.4	26

Source: SWERA

Starting wind speed for large turbines is considered to be 3.5 m/s having this in mind it is possible to install these turbines in more than half million square kilometres in the country. However, for firm power availability from this resource, a cut off speed of 6 m/s is considered. The area of land experiencing wind speeds greater than 6 m/s is practically 90,000 square kilometres translating to 169500TWh of energy awaiting exploitation.

Currently wind installed capacity represents a share of 0.3% of the total county's electricity generating installed capacity despite the enormous potential. The government of Kenya has received several offers to develop wind power in the past years. By December 2016, the government of Kenya through 5000+ MW plan expects to increase its wind electricity generation to 630MW. Currently the installed capacity is merely 25.7MW from wind farms located at Ngong operated by KENGEN.

There are a number of areas in Kenya considered promising and therefore warrant further wind speed mapping to establish their potentials. These areas include Aberdare Mountains, Mount Kenya regions, rift valley escarpments, Marsabit District, the coastal region and lastly the North Eastern Province spanning to Ijara District.

Several wind projects have been lined up while others are under different stages of development. Some of the on-going wind projects include Turkana Wind Park that is expected to have an installed capacity of 300MW, Kipeto Energy Wind Park, Kinangop Wind Park, Ngong Wind Park which is an expansion of the already existing wind power plant and Meru Wind Park which is in planning phase. Table 12 shows the list of existing and proposed wind projects in Kenya.

Table 13 Existing and Proposed Wind Projects in Kenya

Project Title	Project Location	Capacity (MW)
Existing		
Ngong Wind 1 Phase 2	Ngong Hills	6.8
Ngong Wind 2	Ngong Hills	13.6
Proposed and under development		
Lake Turkana Project	Turkana Kenya	300
Isiolo	Isiolo Kenya	50
Prunus	Kajiado	50
Kinangop	Nyandarua	60
Meru Wind Farms	Meru	100
Kipeto	Kajiado	100
	Total	680.4

Source: Kenya Power Sector Medium Term Plan 2015-2020

5.1.4.1 Wind Energy Challenges

In spite of the enormous wind potential in Kenya, wind power expansion has seen several challenges which should be met for affordability of wind systems. Introduction of FIT policy for renewable sources in Kenya has played a significant role in the development of clean energy sources. However, more support is needed in the establishment of long term plans for the deployment of wind energy in the Kenyan energy sector. This include cost benefit analysis on to the extent to which the wind projects should be expanded in Kenya and to attract private sector investment and participation, encouraging financing conditions and policy stability are key.

Other challenges in the wind project development in Kenya are the land acquisition, lack of roads to the potential sites which tend to be far from electricity demand areas and poor transmission lines. There is also the issues of limited auxiliary equipment and availability of technical man power concerning wind generation.

5.1.5 Biomass Resource Potential

In Kenya biomass energy is obtained from forest, woodlands, farm plantations and agro-industrial wastes including wood fuel, agricultural residues and industrial wastes. In rural areas, wood fuel remains the highest supplier of household energy consumption, also relying heavily on wood fuel for energy source are cottage industries including tea factories. This implies that wood production as a source of energy will be intensified for it to be sustainable. A larger percentage of electricity generation from biomass in Kenya comes from cogeneration by the existing sugar factories and from biogas while biofuels are produced from locally grown plants in the country.

5.1.5.1 Biogas Potential

Biogas is produced by the anaerobic fermentation of biomass, municipal wastes and solid wastes. Methane forms a higher percentage of the gases formed during this process, a gas that is combustible and therefore can be utilized for heat and electricity production.

1950s show the introduction of biogas technology in Kenya by the colonial farmers, they promoted two major types of biogas systems; the floating drum and the fixed dome. However, due to the high costs of these two biogas systems their uptake was not very positive. A low costing tubular plastic bio-digester was introduced later in 1990s and was then widely promoted in the western part of Kenya (Simalenga & Gohl, 1996). The introduction of latter technology was aimed at ensuring the reduction in the dependence on wood fuel as source of energy for the rural dwellers.

Potential of biogas in Kenya is expressed in relations to installed capacity, electricity production and heat generated. Installed capacity from different sources employed in Kenya ranges from 29-131MW constituting about 3.2 to 16.4% of the total electricity production. There are two sectors using biomass to generate electricity in Kenya, coffee with a potential ranging from 2 to 18MWe and Sisal with a capacity ranging from 8MWe to 31MWe both using plants based on pulp, wastewater and balls.

Biogas technology penetration rate is still low in spite of the potential benefits that can be derived from it. As at 2008 about 1392 family biogas digester ($10m^3$) had been installed in the country with the production rate of $1.2m^3$ of biogas per day (Government of kenya, 2008). The produced gases from these digesters are for cooking and not for electricity generation.

Adoption of biogas systems country wide has been stalled owing to lack of information regarding its production, potential benefits derived from the systems and the higher costs related with the earlier designs. Problems experienced in the production of biogas include poor design and poor construction of the biogas systems which usually leads to gas pressure problems, poor maintenance and higher costs of maintenance. A summary of energy potential from different sectors using different sources to generate electricity is tabulated in the table 13 below.

Table 14: Biogas Energy Potential by Source

Source	Energy Potential (GWh)
Coffee	12.6-147.6
Chicken	5.8-24.7
Cut flowers	2.4-7.6
Tea	2.7-7.8
Sisal	65.4-284.3
Sugar	18.6-42.8
Milk	1.4-7.2
Pineapple	9.6-26.6
Municipal waste	80.6-512.6
Distillery	1.8-14.9
Meat	0.09-0.6
Pig	1.6-3.8
Vegetable	0.02-0.2

Source Gtz 2010

5.1.5.2 Co-Generation Potential

Primary fuel utilized in the cogeneration in Kenya is bagasse from sugar cane wastes in sugar producing companies. The average annual bagasse production from the existing sugar companies is 1.8 million tonnes with a fibre content of about 18% by weight and a potential export of 830GWh/year. Out of the seven sugar companies in Kenya, only Mumias has managed to be self-sufficient in electricity generation with an installed capacity of 36MW and is exporting 25MW to the national grid. 56% of the 1.8 tonnes of bagasse is used for cogeneration purposes in Kenya. Following the least cost power development plan, the government has plans to expand the cogeneration facilities to realize installed capacity of 300MW. Table 7 shows the estimated potential of power production from the seven sugar companies in Kenya.

Table 15: Power Potential from Bagasse

	Cane Crushing Capacity (Tonnes crushed /Day)		**Bagasse Available (Tonnes/ Day)**		**Power Generation (MW)**		**Electricity Energy Potential (GWh/Year)**		**Internal Usage (GWh/Year)**	
Sugar Factory	Current	potential	Current	potential	Current	potential	Current	potential	Current	potential
Chemelil	2,500	7,000	950	2,660	10	29	48	156	14	47
Muhoroni	2,200	4,000	800	1,720	9.8	19.8	35	134	7	27
Mumias	7,100	9,135	2,850	3,650	32	47	214	236	52	57
Nzoia	2,600	7,000	1,090	2,940	14	40	52	221	11	47
Sony	3,000	6,500	1,110	2,405	15	37	74	231	16	50
West Kenya	1,320	3,500	488	1,295	5	20	25	109	5	29
Total	18,720	37,135	7,288	14,670	85.8	192.8	448	1,087	105	257

Source: LCPDP-2011-2031

Even though the remaining six companies have sufficient capacity to generate sufficient electricity to meet their electricity demand and even export surplus to the national grid. These companies still depend on the national grid. It is expected that these companies will produce sufficient electricity for their internal use and sell excess to the utility as plans are underway to restructure and to improve both machine efficiency and financial performance with the aim of making them self-reliant in electricity generation. This will likely increase the opportunities for generating electricity from cogeneration to the grid which will ease and reduce reliance on fossil fuels for electricity production.

5.1.5.3 Liquid Biofuels

Biofuels are liquefied energy sources obtained from plants. Ethanol comes from the alcohol group of chemicals prepared by fermentation of sugars and starch in the presence of yeast producing alcohol and CO_2 while biodiesel is manufactured from either fats or oil through trans-esterification and having similar characteristics and composition as the mineral diesel. Biofuels compared to other fuels, are biodegradable and therefore reduces pollution of the environment. The potential of bioethanol and biodiesel in Kenya is huge and underutilized.

A number of plants are currently grown in Kenya capable of serving as sources for biodiesel and bioethanol. Major feedstock which can be sustainably be produced without resulting into competition with food crops are usually considered for biofuel production in Kenya given that Kenya is not food sustainable. These crops include sugarcane, sweet sorghum and cassava for bioethanol production while jatropha, castor, croton and sunflower are used as feedstock for biodiesel.

Development of interest for biodiesel in Kenya is due to higher costs of oil witnessed in Kenya which led to the introduction of Jatropha plants followed by several tests to ascertain it viability in the dry regions in Kenya. To enhance the uptake of jatropha and development of biodiesel production in Kenya, the government committed 500,000 acre of land for cultivation of jatropha, further a draft strategy prepared by government proposes 3% blending proportion for biodiesel to reduce fossil imports by 5% (Kiplagat, Wang, & Li, Renewable Energy in Kenya, 2011).

The oil extracted from jatropha seeds can be utilized straight as vegetable oil in different adapted diesel engines, water pumps and oil presses. A study in Tanzania using the oil from the plant has shown that in specially made lamps and stoves it can replace the use of kerosene which is largely used by the poor rural dwellers (Wiskerke, 2008). This scenario makes biodiesel more attractive to investors in these remote areas.

Castor seeds are also very good source of biodiesel oil. It contains about 40 to 50% oil that can be extracted by crushing the seed in an oil press. Unlike jatropha seeds, oil obtained from castor seeds are viscous hence cannot be used directly and therefore needs blending to reduce the viscosity (Muok, Nyabenge, Theuri, Ouma, & Wakhungu, 2008). Due to it viscous nature, castor oil can also be used as lubricant on moving parts in machinery.

Oleander plant grown at the Jomo Kenyatta University for research purpose has shown a potential source of bio-diesel in Kenya (Joseph, 2007). Introduced in Kenya as an ornamental crop, oleander crop is drought resistant and requires minimum inputs during cultivation time thus making it cheap compared to other plants. Oleander seeds contain about 20% oil and have several benefits such as being an excellent source of nectar for the bee farming, source of firewood and can also be used as animal feeds.

5.1.6 Coal Resource Potential

Heavy companies in Kenya around Athi River rely imported coal. These are five cement industries together with the Magadi Soda Company. The amount of coal imported in the country in 2013 was slightly above 200 000 tonnes. The exploration of coal reserves in the country will greatly benefit these firms as coal will be delivered to them cheaply. Table 15 displays the annual import of coal from 2004 to 2013.

Table 16 Coal Import 2006-2013

Year	2006	2007	2008	2009	2010	2011	2012	2013
Tonnes	171,000	156,000	159,000	138,000	165,200	236.300	213,000	208,900

Source: Statistical Abstract, 2014, Kenya National Bureau of Statistics

The exploration activities of coal in Kenya started in 1940s. The resource has been intercepted a number of times while drilling for other resources in other locations within Kitui County. However, coal exploration did not see any substantive activities until 1999 when serious exploration started with the help of Ministry of Energy and Petroleum in Mui Basin. The exploration activities involved surface geological mapping, geographical surveys, exploration and appraisal drilling and resource assessment.

Coal reserves in Kenya are located within Kitui County. Kitui County is known to have potential for different minerals not only coal but also gypsum, gold, asbestos, garnets, magnesite, silica, copper, graphite, iron ore, vanadium and diatomite. Coal reserves are located in Mui Basin, this location has been divided into four blocks, A, B, C and D. Several wells have been drilled in this division as further exploration is on-going. The table 16 below shows the area and number of wells drilled in each block.

Table 17 Blocks in Mui Basin and Well Drilled

Block	Area(km^2)	Drilled Wells	Coal Intercepted
A (Zombe-Kabiti)	121.5	8	4 Wells
B (Itiko-Mutito)	117.5	8	4 Wells
C (Yoonye-Kateiko)	131.5	56	32 Wells
D (Isekele-Karunga)	120.0	4	2 Wells

Source: MOEP

Feasibility studies conducted in block C have shown that the volume of recoverable coal is more than 400 million tons. Basing on the similarity in characteristics of blocks C and D, the potentials of these blocks are of similar amount. Analysis done on the deposits discovered in Mui basin showed that the coal range in rank from lignite to sub-bituminous with a calorific values extending from 16 to 27MJ/kg.

Blocks A and B where a total of sixteen wells have so far been drilled also has shown occurrence of coal deposits. Out of the sixteen drilled wells, eight has shown coal deposits. To determine available recoverable coal in these two blocks more feasibility assessment need to be undertaken. Of the recoverable coal in block C and D the thickness ranges between 0.3m to 13m while the depth of occurrence ranges from 11m to 320m.

There are strategies by Kenyan government to develop a coal plant in Lamu town at the coast. A 960 MW Power Plant phase one is expected to be commissioned in 2017. This is according to the 2013 Least Cost Power Development plan put in place by the government of Kenya to ensure an energy sufficient country. Under this plan coal is supposed to contribute 2000MW into the 5000MW+ project.

Until the extraction of the local coal reserves begins in Kenya, the commissioned coal fired power plant will utilize imported coal. The coal imports will likely come from South Africa due to its closeness to the port Mombasa.

Coal mining comes with some benefits, to start with, given that the coal deposit exists in the remote areas its exploration and exploitation requires significant infrastructural development for transport and this usually leads to development of roads and rail which will be a major boast for a larger part of Kitui County. Currently most of the roads in this area are impassable during rainy seasons affecting its economic activities. As a source of ingredient for steel and cement production, coal also plays a vibrant role in development of modern housing, transport and energy infrastructures.

Kenya has been considered to have one of the greenest energy mix due to its higher percentages of electricity generation from renewables. With the discovery of coal in the country, it will be very interesting to see whether it will divert to more carbon intensive in her electricity generation. With limited electricity access and unreliable electricity subject to constant blackouts and load shedding, it will be hard to leave the discovered coal in the ground.

5.1.7 Oil and Gas

Exploration of fossil fuel (Oil and gas) in Kenya started early in 1950s with six international oil exploration companies. Drilling of the exploration well started in 1960. The drilling activities continued and by 1992, 30 unsuccessful wells had been drilled. The government intensified the exploration activities in Kenya and by March 2012 gazetted 46 exploration blocks out of which 44 had been licenced to international oil drilling companies.

23 international oil exploration companies are currently exploring the 44 licensed blocks. Presently 39 exploration wells have been drilled, results have not been good with only three wells out of the 39 wells being successful. The three wells which oil has been discovered include Ngamia 1, Twiga South 1 and Etuko 1 while Mbawa 1 has natural gas deposits. More wells are planned to be drilled by a number of these companies which will probably result to the discoveries of more successful wells.

The government of Kenya plans to build a gas power plant where a recoverable natural gas reserve of is obtained. None the less this would take a long time since the infrastructure needed in place for the production of natural gas and the power plant may take up to 10 years. The commercial oil when refined will be used not only in the transport sector but also for thermal power plants for electricity generation.

Tests have been done on the oil discovered in the two out of the three successful wells at Ngamia 1 and Twiga South 1 in Turkana County. The results show a production rate of 5000 barrels of crude oil per day which translates to 794,500 litres of crude oil per day. This production rate is projected to increase significantly upon conclusion of appraisal and subsequent drillings.

5.2 Ranking of Electricity Generation Costs in Kenya

5.2.1 Energy Projects Screening

Screening was done for different energy generating technologies to establish annualized costs of generating electricity. The screening provides an appropriate method for comparing cost of different generating technologies since it captures capital costs, operation and maintenance costs and the plant availability using the plant capacity factor. Plants such as geothermal, coal, nuclear and Gas turbines (Natural gas) are suitable for base load given that they have high capacity factors compared to others nonetheless Gas powered power plants are generally preferred for peak loads due to high operation and maintenance costs associated with them.

5.2.2 Energy Project Ranking

To obtain LCoE of generating technologies considered in the report, a given plant load factor was used. The results are used to rank economically different generation technologies in the country. To obtain a benchmark for comparison purposes, the most attractive is assigned an index of 1 from which all the other technologies are ranked against the cheapest technology. Load factor is chosen from the highest value that can be attained by the technology and it takes into account both the planned and unplanned outages and availability for hydro plants given that Kenya experiences fluctuating water levels in its dams due to droughts and the intermittency of wind resource.

Power plant generation technologies are categorized into renewable and conventional technologies and finally, a combination of all technologies ranking from the most economical to the least economical is done.

5.2.3 Ranking Of Renewable Energy Generation Technologies

For calculation purposes a discount rate of 10% is used and for sensitivity analysis 12% is used.

Table 18: Renewables Energy LCoE at 10% and 12%

Discount rate - 10%			
Candidate power plant	Load Factor	LCoE	INDEX
Geothermal	93%	8.9	1
Biomass Cogen	85%	10.2	0.872
Wind	40%	10.3	0.864
Hydro	60%	10.8	0.824
Solar	25%	15.6	0.570
Discount rate- 12%			
Geothermal	93%	10.4	1
Biomass Cogen	85%	10.9	0.954
Wind	40%	11.7	0.889
Hydro	60%	13.1	0.793
Solar	25%	18.0	0.577

Ranking of generation technologies in the table 17 above shows that the most economical renewable source is geothermal followed by biomass cogeneration for both discount rates of 10% and 12%. The most expensive is solar having an LCoE value of 15.6 dollar cents per kWh. However, this is expected to decline as more research and development is done to improve its efficiency as well as to reduce the production costs of solar photovoltaics components.

5.2.4 Ranking of Conventional Generation Technologies

For comparison purposes, same discount rates have been used for conventional power plants LCoE calculations. The results are tabulated obtained using the available data are shown in table 18 below.

Table 19: Conventional Energy LCoE at 10% and 12%

Discount rate - 10%			
Candidate power plant	Load Factor	LCoE	INDEX
Nuclear	85%	12.6	1
GT-Natural gas	50%	14.3	0.881
Coal	73%	15.6	0.807
Discount rate- 12%			
Nuclear	85%	15.1	1
GT-Natural gas	50%	15.2	0.993
Coal	73%	16.8	0.899

For conventional technologies at 10% discount rate, nuclear is the most followed closely by GT-Natural gas power plant. The cost components affected most by the discount rate is the capital costs and this explained why at 12% discount rate, the LCoE of Nuclear and GT-Natural gas are almost the same. Capital cost associated with nuclear power plant is very high compared to others hence the increased LCoE at higher discount rate percentages. The LCoE of nuclear electricity generating power plant is highly sensitive to the discount rates chosen and the capital costs.

A combination of both renewable and non-renewable electricity cost generation is ranked in table 19 for both 10% and 12% discount rates used.

Table 20 Electricity Generation LCoE Cost in Kenya.

Discount rate - 10%			
Candidate power plant	Load Factor	LCoE	INDEX
Geothermal	93%	8.9	1
Biomass Cogen	85%	10.2	0.872
Wind	40%	10.3	0.864
Hydro	60%	10.8	0.824
Nuclear	85%	12.6	0.706
GT-Natural gas	50%	14.3	0.622
Coal	73%	15.6	0.571
Solar	25%	15.6	0.570
Discount rate - 12%			
Geothermal	93%	10.4	1
Biomass Cogen	85%	10.9	0.954
Wind	40%	11.7	0.889
Hydro	60%	13.1	0.793
Nuclear	85%	15.1	0.689
GT-Natural gas	50%	15.2	0.684
Coal	73%	16.8	0.619
Solar	25%	18.0	0.577

From the LCoE table 19 above, it can be deduced that locally available energy resources are cheaper and more economical compared to imported resources and fossil fuel plants at both discount rates scenarios. The future power generation expansion plan in Kenya should then first focus on locally available resources to generate electricity. The deficit should then be toped up by natural gas, coal and nuclear sources, this will not only save on environmental pollution but also saves on the cost of production. It should also be noted that the LCoE for both wind power and solar power are site specific since they depend on availability of wind and solar resources. System integration costs depend on level of penetration and the flexibility of surrounding electricity systems and this mainly affects wind and solar sources.

Cost of feedstock for biomass feedstock is very central when calculating costs of electricity generation from biomass. In situations where the biomass residue is freely available or at a lower price its LCoE turn out to be very low. A case in which sugar cane bagasse is used as source of fuel at no cost, biomass cogeneration becomes competitive with other sources such as hydro and wind. Natural gas power plants' LCoE is sensitive to the fuel costs which fluctuates from region to region, however, both the overnight costs and costs associated to environments are moderately low. Coal power plants costs are majorly affected by the costs of air pollution in the region where the power plant is situated.

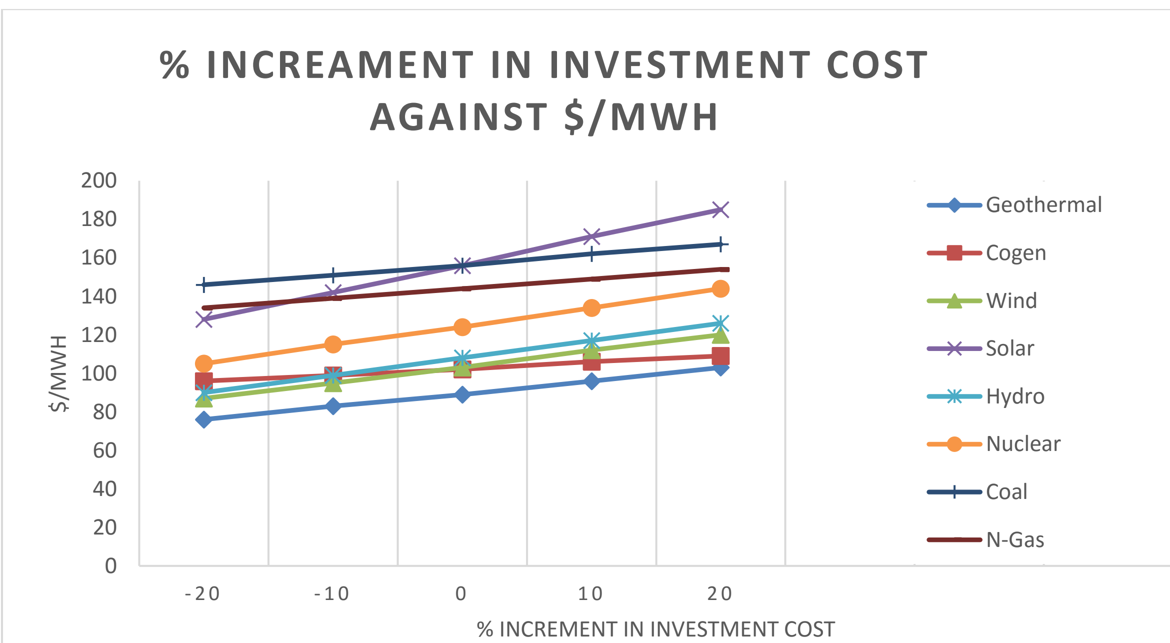
5.3 SENSITIVITY ANALYSIS

Some level of uncertainty always exists in input data due to approximation and the future uncertainty of factors involved. The effects of changes in the input data is looked at in the sensitivity analysis. In this section the following input data are varied to determine their effects on the LCOE of different technologies: Interest rate, investment costs and the economic lifetime of the plants.

5.3.1 Investment Cost

The effect of the investment costs on generation costs is shown in figure 4 below. From the graph, solar power is highly affected by the change in investment costs, reduction in investment costs make solar competitive to both Natural gas plants and Coal. Geothermal remains the economical whether the increment is positive or negative. With continues reduction on investment costs of solar systems solar will likely be more competitive than most of the technologies discussed as more research and development are undertaken on this technology.

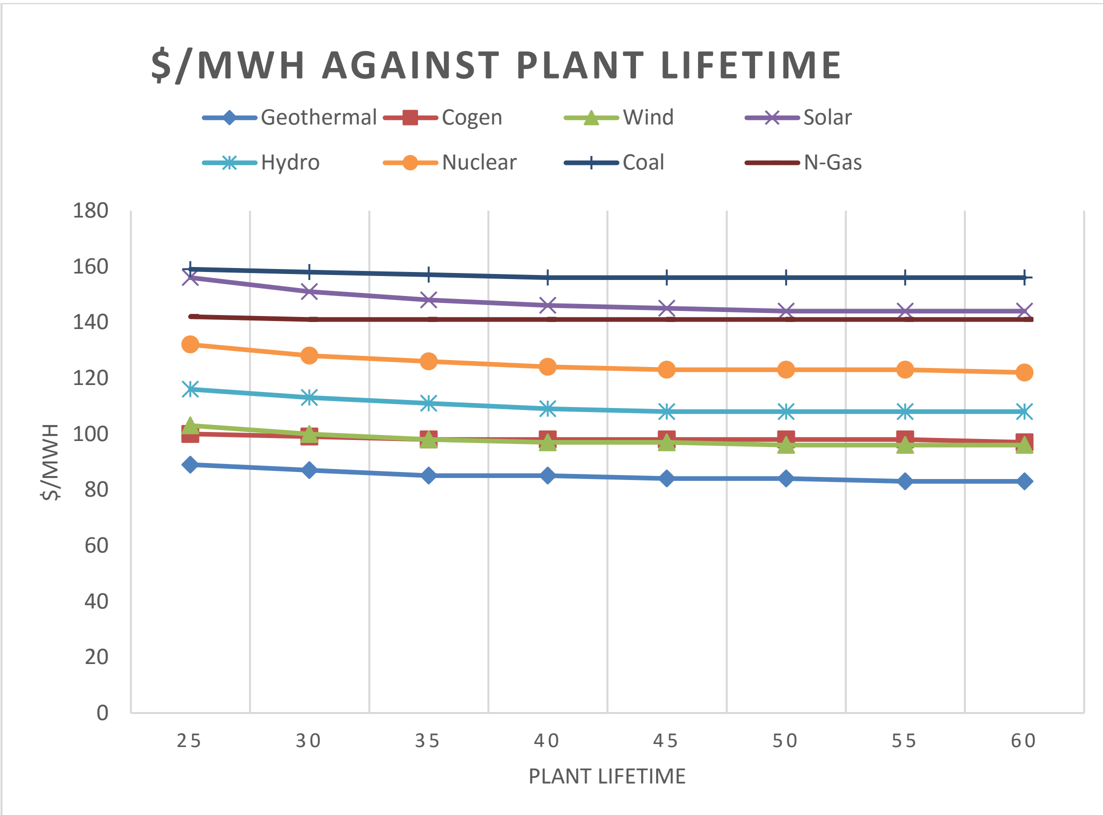
Figure 4: Effects of Investment Costs on Electricity Generation Costs



5.3.2 Economic lifetime

The plant economic life is varied from 25 years to 60 years, and the effects of the plant economic lifetime is illustrated in figure 5 below. Increasing the economic lifetime of the plant from 25 years to 60 years, only decreases the cost of production by only 3$/MWh and geothermal is still the most economical. Decrease in production cost is mostly experienced in the solar technology by increasing plant economic lifetime. Other technologies do not experience any crucial impacts on generation costs with an increase in plant economic lifetime from 20 years to 60 years.

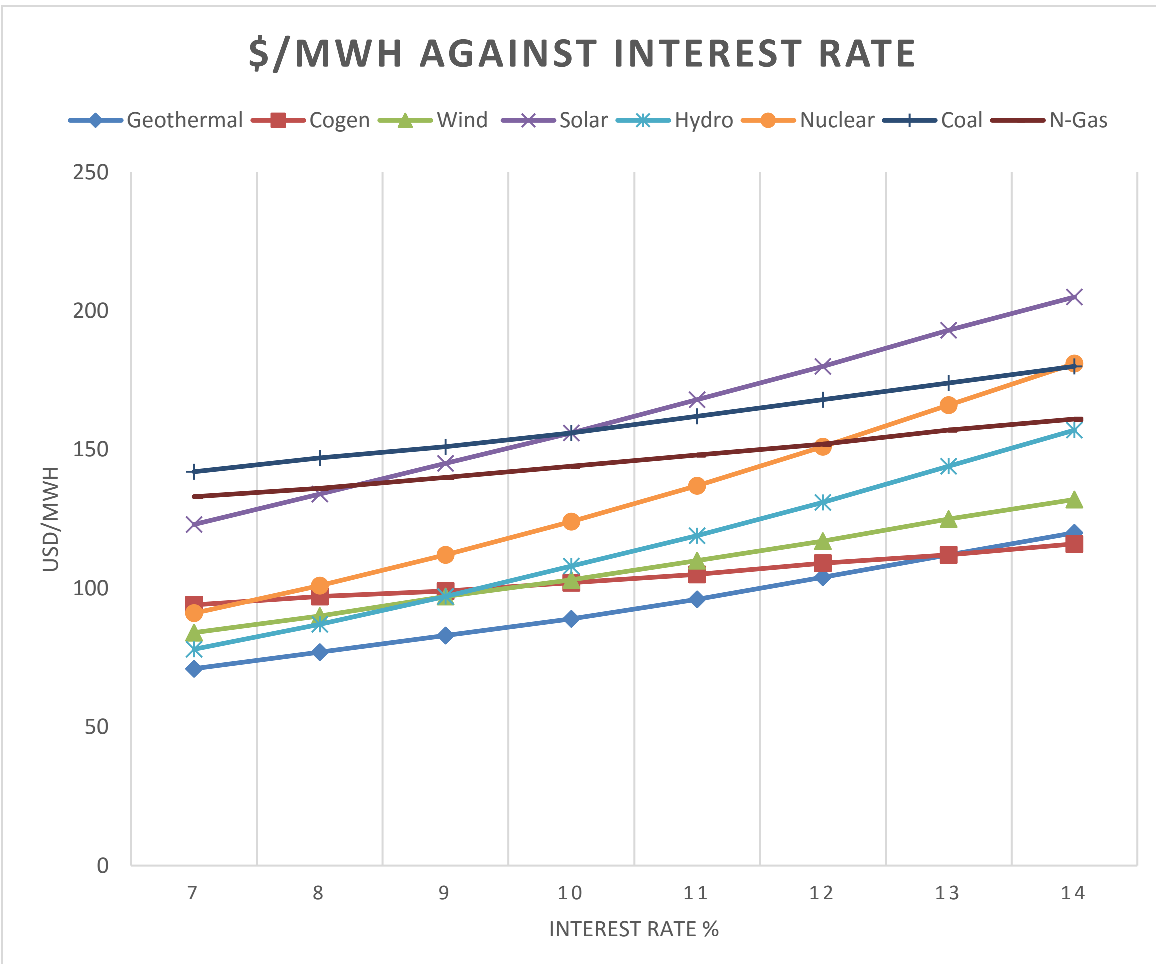
Figure 5: Effects of Economic Lifetime on Power Generation Costs



5.3.3 Interest rate

Figure 6 below illustrate the impact of interest rate on the cost of electricity generation costs. Interest rates are varied from 7% to 14%. Greater effects are felt by capital intensive generation methods as seen with nuclear and solar. At lower interest rates, 12% and below, geothermal technology offers the lowest cost of generation while solar has the highest cost. At rates greater than 13%, biomass Cogeneration becomes more competitive compared to geothermal.

Figure 6: Effects of Real Interest Rate on Electricity Generation Costs



6 DISCUSSION

This section of the thesis explores the benefits derived from continued usage of geothermal source for electricity generation in Kenya. Geothermal potential in Kenya is vast and is capable of meeting the country's electricity demand. Compared to conventional energy sources, geothermal energy is clean thereby presenting a promising solution for the nation and the world at large in solving problems associated with air pollution, global warming, and the volatility of fossil fuels which affects our daily lives.

6.1 Geothermal Utilization Techniques

Primarily, there are three ways in which geothermal energy is harnessed; in Kenya electricity production forms the highest percentage of the geothermal energy use. However, other uses for geothermal resource include direct use application used for agricultural productions and lastly space heating using heat pumps.

6.1.1 Electricity Generation Technology

Generating electricity from geothermal source is centred on the steam turbine coupled with a generator. The steam power expanded in the turbine produces a rotary motion in the turbine coupled with a generator. Tapping of the geothermal energy is done by drilling wells into the potential geothermal reservoirs and channelling the steam or hot water to the power plants by piping systems. Geothermal electricity generating plants depend on the following properties; fluid contents, temperature of geothermal reservoir and lastly the fluid pressure. Depending on these properties geothermal power plants is classified as dry-steam, flash steam or binary cycle power plant.

In dry-stream power plant, steam is piped directly from the wells to the power plants where it is channelled to turbine for expansion. Expanded steam undergoes condensation after which is re-injected to reservoir through an injection well. The mostly used geothermal technology in Kenya is conventional single flash. In flashed steam power plant, the power plant uses reservoir water of temperatures greater than 182^{o}C. The fluid pressure decreases as the hot water flow into the surface resulting into hot water flashing into steam. Steam produced is separated from geothermal fluid and used to generated electricity. Binary cycle plant operates at lower temperatures in the range of 107^{o}C to 182^{o}C. Heat from geothermal water vaporises working fluid in the heat exchanger, vapour produced is then expanded by the turbine thereby producing rotary motion. The exhausted water is re-injected to the reservoir.

6.1.2 Geothermal Direct Use

Processes such as crop drying, greenhouses, industrial heating and house heating can use hot geothermal water to accomplish the required objectives. Reservoirs having lower temperatures are drilled to supply steady hot water flow using of pumps and piping system into a heat exchanger which then delivers the heat for the purpose of direct use. Direct use of geothermal resource can be defined as the utilization of underground hot water to deliver heat to buildings, grow plants mainly in greenhouses, heating water for aquaculture and for milk pasteurization. Geothermal direct use system encompasses of three components namely the production facility from where the heat is obtained in this case a well, the mechanical systems which help to deliver the heat to the space for heating, these are piping systems and the heat exchangers and lastly the disposal system which receives the used geothermal fluid.

6.1.3 Geothermal Heat Pumps

These pumps always maintain almost constant temperature between $10^{o}C$ and $16^{o}C$ using shallow grounds working as sources of energy storage devices. Depending on the condition of the house, heat pumps transfer heat from the building during cooling seasons and vice versa. Heat pump takes advantage on the comparatively constant earth's temperatures at a depth of 10 to 300 ft. and circulates the water through a piping system buried in incessant loops position either in horizontal or vertical configurations for installation depending on the land availability.

Highlighting the benefits derived from geothermal as a source of electricity in this report is not intended in any way to criticize other energy generation technologies majorly the renewable technologies. For a varied portfolio energy generation resources it is essential in energy mix of any given country to reduce reliability on one energy source. This section of the thesis is intended to discuss benefits that makes geothermal a preferred energy source over the others.

6.2 Benefits

6.2.1 Environmental Benefits and Impacts Geothermal Energy

Energy production and development programmes have some degree of impacts to the environment in one way or the other. However, employing geothermal resource to generate electricity have the potential to minimize to a great length these impacts, resulting into environmental benefits for the state and local communities relying on the energy production for development purposes.

Apart from being clean, energy from geothermal is considered sustainable as the geothermal industry development came in an era of advanced environmental awareness. Utilization of geothermal for energy production ensures we have a clean environment in terms of clean air, water and also minimizing the solid waste and land use for energy production.

Kenya's geothermal power generating plants are expected to meet environmental regulations and standards as stipulated in by the WHO standards and regulations. WHO (2000) specifies that on a full day average, concentration of H_2S gas emitted should not go beyond 0.1 ppm, it is evident that with geothermal resources these standards and regulations can be met and even exceed when generating electricity. Geothermal plants clean development mechanism projects in Kenya in Menegai and Olkaria are some of the power plants showing lower emissions.

6.2.1.1 Meeting clean air standards

The strict clean air standards can be met by use of geothermal plants. Carbon dioxide and SO_2 emissions are usually low with almost zero nitrogen oxides emitted. Traces of small quantities of gases emitted by the geothermal power plants are usually not the by-products of power generation rather are natural and negligible compositions of geothermal resource reservoirs. Even if a geothermal plant is not constructed at these locations, these gases in the long run will find their way out into the atmosphere but at a slower rate.

Emissions from flash systems in Kenya is mainly water vapour while few binary systems installed emit almost zero gases as the systems run under a closed system. CO_2 emitted by the geothermal plants is not considered pollutant but a greenhouse gas and comparing the amount produced to that of fossil fuel plant is much less. The carbon dioxide emissions by these plants are reduced by reinjection of used geothermal fluid back to the reservoirs for sustainability of the resource. It is expected that by 2019, geothermal installed capacity will be 1000MW and this will greatly help in reduction of greenhouse gas emission of carbon dioxide to almost 3.9 million tonnes on a yearly basis (Pius, 2009).

Survey done by IGA on geothermal power plant concerning the composition of CO_2 showed that the amount of carbon dioxide produced ranges between 4 g/kWh to 740g/kWh and the weighted average of 122g/kWh. Based on weighted average the CO_2 emission comparison for geothermal plant and fossil fuel plant is shown in table 21.

Table 21: Comparison of CO_2 Emission by Power Source

Power source	Efficiency	CO_2 Emission (g/kWh)
Geothermal	35	122
Coal	35	915
Fuel Oil	35	760
Natural Gas Combined Cycle	60	315

Source: International Geothermal Association (IGA), 2002

The volumes of non-condensable gases emitted to the atmosphere depend upon the characteristics of the available reservoir to be utilized and the technology used. Binary plants because of their closed loop system will virtually release no gas to the atmosphere, dry and flash technologies release water vapour containing non-combustible gases. Re-injection process reduces the possibilities of the emission of these gases to the atmosphere.

H_2S gas released by the geothermal fluids characterized by pungent sulphurous odour is a usual manifest of natural hot springs. Emission of hydrogen sulphide gas from the geothermal plants is usually below 1 part per billion and ranges between 0.03- 6.4g/kWh thus considered not harmful to the community around living around the plant (KAPA systems, 2000). A report done by Argonne National laboratory conclude that geothermal plants are one of the cleanest energy forms, it further points out that binary plants have negligible emissions. Average emission levels from Olkaria power plants to the ambient atmosphere is at 1-10ppm which is below the World Health Organization limits. Table 21 shows the amount of emissions by different energy technologies.

Table 22: Estimated Emission Levels By Energy Source of Power Plants

[lbs/MWh]	Dry Steam	Flash	Binary	Natural Gas	Coal
CH_4	0.000	0.000	-	0.0168	0.2523
$PM_{2.5}$	-	-	-	0.1100	0.5900
PM_{10}	-	-	-	0.1200	0.7200
SO_2	0.0002	0.35	-	0.0043	18.75
N_2O	0.0000	0.000	-	0.0017	0.0367

Source: EIA 2013, Climate Registry 2012

6.2.1.2 Replacing Base load thermal plants

Geothermal plants are considered firm power source for the reason that they run for 24 hours in a day irrespective of prevailing conditions. When built and maintained well, they can generate electricity for longer time. Olkaria 1 Built and commissioned in 1981is still under operational extracting both steam and brine for electricity generation. This power plant has seen additional units with an installed capacity of 150.5MW. Compared to other renewable sources, geothermal electricity generation technology is proven both technically and commercially therefore low degrees of technological risks are involved. To add on that geothermal plants have capability of scalability to over 50MW under a portion of land and negligible environmental impacts compared to other sources.

Currently over 31% of electricity generating installed capacity comes from burning fossil fuels[1]. Due to frequent droughts experienced in Kenya which has affected power production from hydro power stations, these fossil fuel fired power plants have been used for baseload power purposes. With regards to changing environmental regulations and economic changes, most of these fossil fuel power plants would be reduced to emergency or backup power plants.

Of all the available energy sources for baseload power production, geothermal stands out top, it has the least carbon footprint. Geothermal plant under operational emits negligible carbon dioxide to the atmosphere with the emission ranging from 59-396lbs/MWh compared to a natural gas fired power plant which emits 861lbs/MWh[2]. More carbon dioxide is emitted to the atmosphere when

[1] Kenya power sector medium plan 2015-2020
[2] U.S. EPA 2011

burning biomass material compared to burning of fossil fuels, however, evaluating the carbon net footprint usually prove challenging.

6.2.1.3 Land Footprint

Land use for electricity generation from geothermal is usually very small compared to other sources. Unlike other sources such as wind, solar and biomass sources which require large tracts of land to generate significant amount electricity, geothermal power plants usually exploit a concentrated underground resource. Biomass forms the largest form of primary energy in Kenya and is mostly consumed as firewood from forests and woodlands. However, a small percentage is used to generate both electricity and heat. The conversion efficiency is usually very low and therefore large quantities of biomass fuel is need for this purposes hence the large area needed to grow the biomass source for energy generation. The land use intensity for energy production considering different technologies per TWh is summarized in the table 22.

Typically, geothermal plant would require wells and well drilling process impacts the use of land. Nonetheless, advanced drilling technology such as slant and directional drilling limit these impacts associated with drilling as well as allowing many wells to be drilled from one location thus reducing the quantity of land needed for geothermal well drilling, road construction and for piping systems as the plant is usually near the wells.

Table 23: Land Usage per TWh

Technology	Geothermal	Coal	Solar Thermal	Natural gas	Solar PV	Petroleum	Hydro	Wind	Biomass
Km2/TWh	7.5	9.7	15.3	18.6	36.9	44.7	54.0	72.1	543.4

Source: McDonald et al, 2009

6.2.1.4 Reliability

Being renewable source, production of energy from geothermal is considered predictable and extended life. Electricity generation from geothermal source does not rely upon the transitory environmental conditions. Due to this, geothermal capacity factor is usually higher than any other energy source as it can generate electricity 24 hours, seven days a week. Comparing capacity factor of different energy sources, a report done by EIA ranks geothermal power with a higher capacity factor of 92%, followed closely by gas power plant having a capacity factor of 87%, coal at 85% and biomass at 83%. The other renewables such as wind and solar photovoltaics have capacity factors of 34% and 25% respectively[3].

Geothermal wells can perform well beyond their life span demonstrating their reliability. The first ever geothermal well drilled by Prince Piero Ginori in Italy in 1904 and commissioned in 1913 is still producing steam for electricity production up-to date. In California a geysers field has been exploited reliably from 1960s to date and energy from this field counts for about one-fifth of green energy produced to date in California[4]. In Kenya, Olkaria 1 field has performed beyond expectation; the first plant in this field was commissioned in 1981and the wells are still producing past the life span. Today more additional geothermal power generating units have been constructed in this field raising the installed capacity to 150MW.

Reliability and longevity of geothermal source demonstrate the level of reliability of this resource as well as the technology employed in its exploitation. The technology used in exploitation of geothermal resource is more or less similar to the technology which has successfully been used to drill oil and gas hence considered mature drilling technology.

Electricity generation from solar and wind are ground-breaking technologies which will play very important roles in changeover to green energy economy and help lessen consequences related to global warming already being experienced. None the less their main undoing is the dependency on the prevailing weather conditions. Cloud cover above the sky and the changes in wind patterns will affects the availability of electricity generation from these sources.

6.2.1.5 Minimal Solid Wastes

Operations of geothermal plants produces little significant wastes. Nevertheless, geothermal fluids certain by-products having valuable minerals that can be recycled and utilized. The by-product contain dissolved salts that can crystallized and silica which can be used for cosmetic purposes as in the case of the Olkaria spa in Kenya and the Blue Lagoon in Iceland. The reinjection of separated and condensed fluid back to the ground minimizes the release of geothermal fluid to the environment and unlike fossil fuels; there is no storage required nor do transportation facilities for

[3] U.S EIA, 2013
[4] Calpine, 2012

geothermal brine hence no stress of disposal. Drilling of geothermal wells produces drilling mud wastes which is lost during circulation in the wells. Other Products forming solid wastes during drilling are cements and petroleum products mainly from fuels and lubricants used. Cement on the other hand is not considered harmful, although some of its constituents such as silica may be hazardous.

6.2.1.6 Lessening of Effects of Climate Change and Drought on Hydroelectric Power Units

Kenya needs a more robust and resilient ways of addressing the issue of drought which usually induce electricity production crisis. Mature renewable energy option having multiple benefits are the best candidates whose development can supplement power generation from hydro. Geothermal, cogeneration from sugar industries, small hydro and wind offer the best option since these resources are extensively availably. Apart from being environmental friendly, these resources provide added benefits such as creation of jobs for the local and reduction of oil dependency. Geothermal energy is the way to go, with various glitches facing the energy sector in Kenya coupled with the global warming issues; this resource has social, economic and environmental related benefits. Its implementation would reduce the reliance on both fossil fuel plant and hydro which will protect power sector from volatility in oil prices and droughts affecting hydropower generations in Kenya.

6.2.2 Economic Impacts and Employment Benefits

There exists an interrelation between employment benefits and economic development. When planning for a geothermal power plants, expenditures for equipment and services are made same as for the royalties and taxes. The expenditures will stimulate job creation direct and indirect which will then result into more economic activities thus increasing the tax revenues.

6.2.2.1 Carbon Credit

This refers to sale of gases contributing to global warming, not released to the atmosphere due to installation of environmental friendly power generation systems. Carbon trading involves industrialized countries providing funds for clean and environmental friendly energy projects within third world countries with an aim of meeting the emission targets as set under mechanism of clean development, a treaty in the Kyoto protocol. With the high potential of geothermal resource in Kenya, the country is expecting to benefit from this mechanism for revenue generation from it geothermal project located in Menegai by selling the carbon credit and this can be extended to all planned geothermal projects in Kenya.

Countries in developing world get credited depending on the level to which less carbon is emitted to the atmosphere as par the standards set by the UN Framework Convention on Climate Change. Kenya so far has received a total of 540 Million Kenya shilling from carbon trade coming from the five projects namely bagasse based Cogeneration project based in Mumias sugar, from both Turkana Wind project and Abaredares small scale reforestation and with the expansion of Olkaria 2 by Kenya electricity generation company as well as Olkaria phase 2 expansion project (Joel & Dancun, 2013).

An agreement signed by Kenya electricity generating company and World Bank in 2011 was to purchase 900 000 tons of carbon generated from one of the six existing Clean Development projects in the country, these projects are: Olkaria 2 third unit, Eburru, Kipevu combined cycle, Kiambere and redevelopment of Tana power plant station.

6.2.2.2 Well Head Units and Early Generation

The reason for lower exploitation of geothermal source for electricity production worldwide is time taken for development of geothermal projects, this situation always results to financial pressure on the projects. Well head technology was introduced in Kenya to lessen time taken for putting up a geothermal plant, between drilling and the start and completion of a central power plant. This technology harvests the capped steam as soon as it is available for power generation there by generating income before installing a central power plant. This technology is embraced by KENGEN to realize early generation hence a return on investment.

Wellheads attractiveness are in their characteristics. They are the much needed interventions Kenya’s power sector needs to moderate challenges associated with limited development of geothermal energy. Some of these challenges include inadequate supply due to slow capacity addition rate, the over dependency in hydropower, long time taken to develop power plants, high power costs, low private participation and power sector, low rate of electricity access among others.

Wellheads have the capability to provide solutions for these problems, to start with the wellheads do not require auxiliary power to start its generator hence can be installed without considering electric network and therefore very good for off-grid purposes. These units also have the possibilities of attracting investors because they shorten time between exploration and generation of a geothermal project. Secondly, wellhead designs are based on standard manufactured components which allow for reduction of lead time and early power online. It is possible to deliver online power from these wellheads within a year of ordering for the units hence a rapid deployment (GEG, 2015).

Risks related with wellhead turbines are low and the units are transported in customized containers. These units are designed to operate independently, in the event of well failure the units can easily be decommissioned and translocated to the next available discharging well thereby maximizing on the return on investment. Based on the standard manufactured components the wellhead design like C64 from Green Energy Group can produce over 6.4MWe. These designs are capable of reducing cost per megawatt because they enable a highly competitive price, lower maintenance costs and easy access of spare parts.

6.2.2.3 Employment Benefits

Geothermal generation provides a variety of work opportunities. Some of the jobs opportunities in the geothermal energy field include exploration for and drilling, manufacturing of turbines and generators, power conditioning components and lastly operational and maintenance, the wages and salaries earned by the geothermal plant employees leads to additional job creation in the local economy. The general rule of thumb in provision of labour for the development of these projects is to maximize the use of local labour.

Geothermal employs about 1000 permanent staff. Facilities such as provision of security and cleaning are outsourced from the local communities, large amount of informal labour is outsourced to the local communities but based on casual terms during maintenance and plant construction. Construction phase of Olkaria 1 show an influx of workers and this over stretch the limited resources on the local communities. It is evident that the construction phase of geothermal plants requires more workers compared to operation and maintenance stages. Increase in labour force in a given location would result into an increase in rental houses required and transport system. It is estimated that a total of 920 temporary labour forces was used during the construction of Olkaria 2.

7 CONCLUSION

The aims of this thesis was to identify and analyse the energy sources potential in Kenya for electricity generation as well as the most economical energy source and finally, to establish the benefits derived from increased electricity generation from geothermal heat using various techniques. The LCoE model used provided robust results as it included timing of investments, both air pollution and climate externalities costs as well as different discount rates for sensitivity analysis.

Geothermal is the most economical source in Kenya followed by biomass cogeneration, wind and hydro in that order, electricity generation costs of geothermal with a capacity factor of 93% is 89 $/MWh, which is the least cost option of the eight electricity generation technologies considered. To foster growth of these resources, the country's energy policy makers are coming up with better policies and already there exists better feed in tariffs for renewable energy sources with an aim of luring investors to invest in energy generation from renewables. Each of these electricity generating technologies experiences some challenges. Wind and solar are not dispatchable and intermittent. As a result, a lot of stain is put on the national grid and this requires considerable storage facilities or a backup diesel power plants which are very expensive.

To mitigate challenges associated with individual energy source, an all-inclusive energy mix from all the available energy sources should be encouraged. Coming up with an all-inclusive energy mix together with the already existing energy infrastructures, the country will be capable to generate and power its future at an affordable cost.

Kenya is not considered a larger GHG emitter due to its energy mix which is made up of a higher percentage of renewable. However, this is poised to change as the country might move towards a more carbon intensive energy mix. With the discovery of fossil fuel deposits in different parts of the country and plans to construct and commission of coal and diesel power plants, the emissions from conventional power plants will increase the country's emission level and to minimize emissions from the coal power plant, Kenya intends to utilize Clean Coal Technologies.

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