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Future of Kenyan Electricity Generation

An analysis of physical and economical potential and least cost sources

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Abstract

Kenya has always had a renewable energy mix, with over 80 percent of electricity generated from renewable sources. As the country continues to develop, and in order to meet the growing demand for electricity, Kenya is considering using non-renewable sources. There are many studies on energy in Africa, and some on the potential for renewable energy in Kenya. However, there are currently no comprehensive studies on the physical potential and costs of electricity generation in Kenya. This paper seeks to fill this gap.

This paper calculates the physical and economic potential for three electricity sources, solar, wind and biomass for Kenya. Then the Levelized Cost of Electricity is calculated for eight energy sources: solar, wind, geothermal, biomass, diesel, nuclear, coal and gas. In order to ensure robust results, this paper conducts two sensitivity analyses, one using a high and low discount and escalation rate, and one using high, medium and low carbon tax rates. Based on the results of these analyses, the most abundant and economical energy sources identified in this paper are wind, nuclear, biomass and solar.

The paper then discusses the benefits and challenges of each of these sources. The benefits of the sources range from modularity to base-load capacity, and the challenges from intermittency to location dependency. Creating a mix of the four identified sources effectively mitigates most of the challenges of these sources. However, to mitigate some issues, such as the political nature of nuclear power, vigorous government and safety programs must be in place.

The final issue the paper discusses is the issue of coal in Kenya's electricity future. Since the discovery of economic reserves in 2010, Kenya has been debating the role coal will play in its future. The discussion debates the future of coal in Kenya from both a developmental and environmental perspective.

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1. Introduction

Fossil fuels have traditionally comprised the main source of fuel for countries undergoing economic development. Carbon intensive coal fire plants built Europe and North America. Today however, concerns about the impact of carbon dioxide (CO_2) and other green-house gasses (GHG) have created a new energy development reality for the world. Developed nations are beginning to flock to *green energy* technologies, such as wind and solar. Developing countries are told to follow, but these green technologies often come at higher initial prices and present challenges of their own, such as intermittency.

As the world has continued developing, global energy consumption has risen by 55 percent over the last 20 years (BP 2014). This rise in consumption is driven mostly by development in Asia, specifically China and India. Energy consumption has greatly increased in these countries in line with the continued economic growth and development. The future growth of energy consumption will be in Africa where the current population of one billion persons will double over the next 40 years ("2013 World Population Data Sheet." 2013). This projected growth in population, and economic development will see the global demand for energy increase 41 percent over the next 20 years (BP 2014).

Growing concerns about climate change are now influencing energy production policies around the world. Denmark and Germany, for example, are turning to renewable energy sources such as wind and solar to reduce their GHG emissions. Other nations, such as Canada and Norway, have based their energy systems on hydro-electricity. The developed world is now looking to the developing world to change the energy sources to green alternatives for development.

This thesis looks at eight electricity sources in Kenya, with cost analysis done for each. These sources are solar, wind, geothermal, biomass, diesel, nuclear, coal and gas combined cycle. However, due to limited availability of data the physical and economic potential will be determined for three sources, specifically solar, wind and biomass. The paper identifies the most abundant and economical sources for Kenya's future power generation.

The next sections give a background on Kenya, the electricity generating mix and the development of the electricity sector in Kenya.

1.1 Kenya Background

Kenya is a developing country in East Africa, surrounded by Somalia, Ethiopia, South Sudan, Uganda, Tanzania and 536 kilometers (km) of coastline on the Indian Ocean. Kenya covers an area of 580 367 km^2, with 11 227 km^2 covered by water ("CIA World Factbook." 2014). The Great Rift Valley runs through the country, separating the low arid plains in the east with the fertile plateau in the west ("CIA World Factbook." 2014). Less than 10 percent of the country is arable land (9.48 percent), and permanent crops cover less than two percent of the land (1.12 percent). Paradoxically, the fertile Kenyan Highlands is one of the most successful agricultural regions in the whole of Africa ("CIA World Factbook." 2014).

Kenya is the 31st largest country in the world in terms of population, with a population of 45 million ("CIA World Factbook." 2014). Kenya's population is young, with a median age of 19. Forty-two percent of the population is under the age of 14, with the next largest age bracket of between 25 and 54 years old, comprising 33 percent of the population ("CIA World Factbook." 2014). Population growth is slowly decreasing, and is now at 2.1 percent, however, electricity demand is set to grow 665 percent[1] over the next 16 years.

The natural hazards Kenya faces are recurrent drought in dry seasons and flooding in rainy seasons ("CIA World Factbook." 2014). These threaten not only the population living in the areas but also the energy and electricity supply. The Great Rift Valley is famous for its unique geothermal activity, not unlike Iceland, and has the potential to provide a large amount of electricity.

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[1] Based on the anticipated peak load growth in the National Energy Policy page 71 ((19 199 – 2 511) / 2 511 = 6.6459577)

Kenya has one of the greenest electricity generating mixes in the world, with 80 percent generated from renewable sources (Kiplagat, Wang, and Li 2011). The major sources of renewable electricity are hydro and geothermal. While hydropower currently accounts for 44 percent of the total power generation ("The World Bank DataBank." 2014), occasional droughts affect the viability of hydro. In 2007 as much as 52 percent of Kenya's electricity came from hydroelectric sources, but by 2009 that number dropped to 32 percent due to drought.

Kenya faces the challenge of increasing the amount of electricity produced to fuel development through internal resources. Additionally, the country needs to work toward ensuring energy security, particularly by improving resistance to weather and climate changes. The government must foster competitive markets in the energy sector, and ensure prices remain low enough so that the poor can afford to participate in the energy market (*National Energy Policy.*2012).

Currently 50 percent of urban and only 5 percent of rural population has access to the electricity grid ("Energy Profile Kenya." 2013). In order to develop further, Kenyans will need to have greater access to grid electricity and energy consumption. The government is working towards increased access to electricity for both urban and rural communities through its 'Vision 2030', which is a plan to develop the nation in all areas and meet the Millennium Development Goals. As a part of this plan, Kenya is aiming to increase the rural electrification to 40 percent by 2024 ("Energy Profile Kenya." 2013).

The Ministry of Energy and Petroleum (MoE) oversees the electricity market. Listed in Table 1.1 are the current sources of electricity in Kenya.

Table 1.1

Sources of Electric Power Generation		**Installed Capacity**		**Annual Generation**	
		(MW)	**Percentage**	**(GWHrs)**	**Percentage**
Renewable Energy	**Hydro**	762	47.8%	3,427	46.9%
	Geothermal	198	12.4%	1,453	19.9%
	Wind	5	0.3%	18	0.2%
	Cogeneration	38	2.4%	87	1.2%
	Imports			30	0.4%
	Total	1,003	63.0%	5,015	68.7%
Fossil Fuels	**MSD**	452	28.4%	1,976	27.1%
	Gas Turbines	60	28.4%	1	0.0%
	HSD	18	1.1%	44	0.6%
	Emergency Power Plants	60	3.8%	267	3.7%
	Total	590	37.0%	2,288	31.3%
Installed Capacity and Units Generated		**1,593 MW**		**7,303 GWHrs**	

Source: (*National Energy Policy.*2012)

The literature on this topic identifies a well-established link between economic growth and energy consumption. As growth and development of a developing country increases, so does the demand for energy (Kaygusuz 2012). In the case of Kenya, this is very evident when looking at electricity demand. Table 1.2 shows the electricity supply and demand from 2004/5 to 2010/11, alongside the country's GDP demonstrating the economic growth. This table illustrates the similar rate of growth for both the economy and consumption of electricity.

Table 1.2

	2004/05	**2005/06**	**2006/07**	**2007/08**	**2008/09**	**2009/10**	**2010/11**
Energy Generated (GWh)	5,347	5,697	6,169	6,385	6,489	6,692	7,303
Energy Sold (GWh)	4,379	4,580	5,065	5,322	5,432	5,624	6,123
Peak Demand (MW)	899	920	987	1,044	1,072	1,107	1,194
Number of Consumers	35,144	802,249	924,329	1,060,383	1,267,198	1,463,639	1,753,348

Source: KPLC Annual Report and Financial Statements, 2011.

The relationship between energy and development is further exaggerated as more of the country is 'electrified' or given access to electricity. As of 2011, the average connectivity to the grid was 28.9 percent of Kenya's population. This is nearly double the figure for 2004, when only 15 percent of the Kenyan population was connected (*National Energy Policy.*2012).

The Vision 2030 goals are building towards having a stable electricity supply from a variety of sources. The plan indicates that the largest portion of electricity should come from geothermal (26 percent), followed by nuclear (19 percent); coal (13 percent); wind (9 percent); gas turbines (LNG) (11 percent); thermal plants (9 percent); hydro (5 percent); and import the rest (8 percent) (*National Energy Policy.*2012) This plan is implemented through Feed in Tariff (FiT) structures, liberalization of the Energy Supply Industry (ESI) market and other government incentives.

1.2 Kenya Power Market Development

In 1881, the Sultan Seyyid Bargash bin Said bin Sultan of Zanzibar set up the first steam driven electric generating plant to light his palace. This plant became the center of the lighting and power industry in Mombasa. In 1922, private investors formed the predecessor to the Kenya Power and Lighting Company, the East African Power and Lighting Company (EAPLC). In 1954, the Kenyan Government became a major shareholder in the ESI for the first time, and from then on played an active role in the development of the ESI. (*Annual Report 2011/2012.*).

As early as 1957, Kenya explored its geothermal potential in the country's Great Rift Valley. However, it was not until 1981 that production of electricity from geothermal first came online. Today the country benefits from 212MW installed capacity, with goals for 5000MW of installed capacity of geothermal by 2030 (Matek 2013). Geothermal is a stable source of electricity for Kenya; however, the high capital costs make it difficult to increase capacity as a percentage of total energy sources.

The oil price hikes in 1973, 1974 and 1979 increased Kenya's oil import bill by 244 percent over the 1973 level. In response to these oil shocks the MoE formed in 1979 to develop policies for energy and electricity and explore the country's energy resources ("Ministry of Energy and Petroleum." 2013). After several reorganizations, the Ministry of Energy's goal is to develop all potential energy sources, and oversee the statutory bodies in the energy sector.

In the 1990s, along with the global wave of private participation in infrastructure, Kenya officially liberalized its power market in 1996 in an effort to reform the power sector (Eberhard and Gratwick 2005). This change meant that all power projects were now open for competitive bidding from private firms, and no national generator would receive preference. In 1997 the Electric Power Act was introduced, and created an independent regulator for the ESI (Eberhard and Gratwick 2005) to shift control out of the government's hands. Also in 1997 the EAPLC split by dividing the major functions of the firm: the Kenyan Electricity Generating Company Limited (KenGen) is responsible for generating electricity and the Kenyan Power and Lighting Company (KPLC) responsible for the transmission and distribution systems for electricity (*Annual Report 2011/2012*). The Kenyan government currently owns 51 percent of the KPLC, maintaining some measure of control over the country's distribution lines (Eberhard and Gratwick 2005).

In 1998 the Electricity Regulator Board (ERB) began operations with the mandate to monitor all Independent Power Producers (IPPs) (*Annual Report 2011/2012*). By this time there were no government subsidies for power generators, excluding those under the rural electrification program (Maweni 2000). The World Bank supported the reorganization of the ESI by extending a loan to Kenya (Maweni 2000). These reforms aimed to create better functioning legal, regulatory and institutional frameworks; providing reliable, efficient and sustainable power, increasing population access to electricity and improving power distribution efficiency. The reforms also created a competitive electricity market for public and private generators, transmissions companies, distributors and sales players (*National Energy Policy.*2012).

Kenya has been heavily reliant on hydropower. In 1999 when the severe droughts started, the MoE needed to negotiate with the World Bank for funding for three emergency diesel-fired power plants (Eberhard and Gratwick 2005). This was the first time KPLC sought more expensive, fossil power sources. The World Bank estimated that the drought would cost up to 6.5 percent of the GDP over the nine months between rainy seasons (Maweni 2000). This drought severely limited the amount of electricity produced, and greatly impacted agriculture and manufacturing.

Through the World Bank funded program Kenya considerably mitigated the impacts of the drought. Since the early 2000s, Kenya has intentionally diversified its energy mix. One of the way Kenya has diversified is by setting up the Geothermal Development Company (GDC) in 2008 to fast track the development of the country's plentiful geothermal potential ("Geothermal Development Company." 2014).

Since 2004, the growing and developing economy has led to a growing demand for electricity. The number of consumers more than doubled between 2004/5 (735 144 consumers) to 2011 (1 753 348 consumers). The peak demand has grown from 899 MW (2004/5) to 1 194 MW (2010/11), and this is expected to grow to 15 026 MW by 2030 (*National Energy Policy.*2012).

Kenya is taking an active role in the electricity development of the area, and is one of the founding members of the East Africa Power Pool (EAPP). The EAPP aims to facilitate interconnectivity and integration of the power markets and create the Common Market for Eastern and Southern Africa (COMESA). The EAPP formed in 2005 and has coordinated projects to foster coordination. It has laid the groundwork for the interconnectivity projects that will be commissioned between 2014 and 2017.

The key players in the Kenyan energy market are: Ministry of Energy (MoE), Energy Regulatory Commission (ERC), The Kenyan Power and Lighting Company (KPLC), Kenyan Electricity Generating Company Limited (KenGen) (70 percent owned by state), Rural Electrification Authority (REA), Geothermal Development Company (GDC).

1.4 Paper Structure

This paper analyzes the physical and economical potential of solar, wind and biomass and the costs of solar, wind, geothermal, biomass, diesel, nuclear, coal and gas to determine the most abundant and economical electricity sources of energy for the country.

Section 2 discusses the relevant literature in three areas: economic development and energy consumption; energy in Kenya looking at the physical potential; and, the cost of energy in Kenya.

Section 3 describes the research question and motivation for this paper.

Section 4 outlines the methodology used in the paper to find the physical potential of solar, wind and biomass, and calculate the costs of electricity generation. The physical potential calculations are based on various physical properties of technologies and the natural resources of Kenya. The direct costs of energy discussed are the levelized cost of electricity (LCOE). This section also discusses the limitations of the methodology and paper.

Section 5 outlines the results of the physical and cost analyses and identifies the four most abundant and economical sources.

Section 6 discusses the benefits and challenges of the identified electricity sources. This section includes an overview of additional indirect costs and factors for consideration when choosing an electricity generation mix, which are not covered in the previous sections. These factors, such as intermittency and transmission losses, are important to consider when developing an energy mix. This section also discusses the future role of coal in Kenyan electricity generation.

Section 7 concludes the paper with recommendations of the most abundant and economical sources of electricity. This section also provides suggestions for future research.

2. Literature Review

The objective of this paper is to find the most abundant and economical electricity sources in Kenya. The motivation for this is question is that finding and building upon a least cost source plan, will enable a country to develop economically and socially, and lift the population out of poverty. The first step is to examine the existing literature for a link between energy consumption and economic development to ensure that the goals of increased development through energy are plausible. The next section includes a review of the literature on the history of energy in Kenya and discusses the literature on the physical potential of energy sources in Kenya. The last section will discuss the literature on the cost of electricity in Kenya and identify the gap in literature that this paper seeks to fill.

2.1 Energy Consumption and Economic Development

The literature on the causal relationship between energy consumption and economic development is well established, but has mixed results for the direction of causality. In the seminal work on the topic, Kraft & Kraft (1978) found a unidirectional causality from gross national product (GNP) to energy, but not from energy to GNP. This means that while a recession affecting the GNP would cause the consumption level of energy to drop, no similar drop in energy consumption would lead to a corresponding drop in the GNP. While examining a similar relationship between energy consumption and real income, Masih and Masih (1996) found that the causality depended on the level of economic development of a country. In less developed countries, such as India, they found a causal relationship, but in more developed economies, such as Singapore and Malaysia, there was no such relationship between energy consumption and real income. These two studies taken together would suggest that in Kenya there would be a bidirectional causal relationship between energy consumption and financial prosperity.

Al-Mulali and Che Sab (2003) found a long run, positive causal relationship between prime energy consumption and economic development. Belke *et al* (2011) also found a bidirectional causal relationship between energy consumption and economic growth. These two studies further establish the link between energy consumption as a driver of economic growth and development. In a recent study, Ouedragogo (2013) found unidirectional causality between GDP and energy consumption and GDP and electricity consumption, but found the relationship differed depending on the period. In the short-run, GDP growth affected energy consumption and electricity consumption, whereas in the long run Ouedragogo found the opposite. Nawaz *et* al (2012) explains that the differences in the variables used and the role of each variable, fuel the ongoing debate in literature about the direction of causality between energy consumption and economic growth.

Regardless of the direction of causality, as Abalaba & Dabiodun Dada (2013) point out, there is a clear link between energy consumption and economic development. Kaygusuz (2012) describes the relationship as a part of a virtuous cycle of economic, social and human development. This study demonstrates a bidirectional relationship between energy and economic, social and human development and clarifies the role of energy in development. The OECD (2007) describes the role of energy as both positive and negative. The positive aspects are not related to the energy itself, but rather the improvement to services and tasks by using energy. The negative aspects of energy relate to the negative externalities of harvesting energy, i.e. emissions from coal, oil and gas disrupting ecosystems. Thus, scholarly research has well established the role of energy consumption in economic development. This paper seeks to contribute to this body of literature by identifying least cost electricity sources in order to spur development.

2.2 Energy in Kenya

Since independence in 1963, Kenya has enjoyed steady economic growth, leaving aside the oil shocks of 1973-1974 and 1979 (Acker and Kammen 1996, 81-111). Since 1963, Kenya has explored and employed many renewable energy technologies, and has become Africa's leader in solar photovoltaic (PV) (Bawakyillenuo 2012). Accordingly, the scholarly literature on point heavily focuses on Kenya's solar potential, uses and market. The Solar PV market began to develop in earnest in 1985 and, according to Acker and Kammen (1996), was poised for this technology to take off. During the late 1970s and early 1980s there was a period of high investment in renewable energy sources in Kenya, due to the oil shocks of the 1970s. Kenya, like most African nations, imports all of its fossil fuels, and during the 1990s the falling Kenyan shilling, rising inflation and a brief period of import tariffs and a value-added-tax (VAT) for renewable technologies, destabilized the economy (Acker and Kammen 1996). This period caused the solar PV market to become significantly less attractive, as the cost of the units skyrocketed. However, international donors supplemented the market, and as the economy recovered, the solar PV market once again took off.

Jacobson (2007) describes the fast growth of the Kenyan solar market as a product of timing and market compatibility. During the 1980s and 1990s when the solar market was growing, there was a movement towards free market thinking, resulting in the establishment of a commercial market for solar technology. The free market ideology rewarded solar, because of the modularity that allowed individual households to purchase units; contrast with a coal plant that requires central management and greater infrastructure (Jacobson 2007).

The other main sources of electricity in Kenya are hydropower, thermal and geothermal according to Kiplagat, Wang, and Li. (2011). In their article these authors discuss each of the potential renewable energy sources: biomass, hydropower, solar, wind and geothermal. They conclude that geothermal will continue to play a big role in electricity generation due to its base-load capabilities. However, hydropower will play a smaller role in the future due to the increasing need for clean water and wind will play a substantial role in the future of electricity generation in Kenya (Kiplagat, Wang, and Li 2011).

Kenya anticipates a GDP growth rate of 10 percent for the next 20 years. This rate of growth will require energy production to triple by 2020 and be six times higher in 2030 ("Vision 2030." 2011). To achieve these goals Kenya will need to tap into all of the available energy sources. In the next section, I review the literature on the potential of renewable energy sources and the newly found Kenyan coal sources to meet these projected energy needs.

2.2.1 Physical Potential of Electricity Sources

Kiplagat, Wang, and Li (2011) give a comprehensive overview of the various renewable energy sources in Kenya and provide suggestions of the potential power to be harnessed from some of these sources. For hydropower, they identify a large potential of between 3000 and 6000 MW for large hydro projects and 3000 MW for small hydro projects (Kiplagat, Wang, and Li 2011; *National Energy Policy.*2012). These authors also identify geothermal as having high potential of 4000 to 7000 MW scattered throughout the Great Rift Valley (Kiplagat, Wang, and Li 2011; "Geothermal Development Company." 2014; *National Energy Policy.*2012; Mariita 2002; Ogola, Davidsdottir, and Fridleifsson 2012).

The solar irradiation levels, or amount of energy from the sun that reaches the earth, describe the potential of solar in the literature. The average solar irradiation is 5 kWh/square meter/day in Kenya, which is equivalent to 250 million tons of oil equivalent (MTOe) (Kiplagat, Wang, and Li 2011; Ondraczek 2013; Acker and Kammen 1996; Jacobson 2007). Although this gives a good indication of the power received, it does not explicitly state the physical or economical potential for solar power in the country.

Wind power potential is similarly described in the literature by quoting wind speeds. Kiplagat, Wang, and Li. (2011) indicate great potential for wind power in some areas of Kenya, where wind speeds are as high as 8 to 14 meters per second (m/s). While this is not directly an indication of the energy potential, these figures illustrate the amount of extractable power in the wind. As part of their wind power discussion, Kiplagat, Wang, and Li (2011) also quote current wind farm capacities. For example, the authors describe the Lake Turkana Wind Farm in Kenya that will have a capacity of 300 MW, and will produce on average 1440 GWh per year; an amount equal to 26 percent of the 2011 annual electricity consumption in Kenya.

There is little written about the potential of fossil fuels in Kenya, only in 2010 did Kenya discover its economical reserves of coal in the Tharkana-Nithi region, located in the northwest of the country. Kenya hopes to exploit this resource, both by auctioning off some of the blocks to foreign parties and by using the coal produced to generate an additional 5 500 MW over the next 40 months (Malingha Doya 2013).

2.2.2 Cost of Electricity

There are relatively few studies on the cost of electricity in Kenya. Abaullaha and Jeanty (2011) studied the willingness of rural communities to pay for grid power versus decentralized renewable technologies. They found that the communities were willing to pay more for grid power, because of its perceived stability and assistance provided by power companies. This is an interesting result. In a related study, Kirubi, Jacobson, Kammen, and Mills (2009) identified community led micro-grids based on decentralized renewables as one of the best solutions for rural electrification. However, Kirubi, Jacobson, Kammen, and Mills (2009) also note that complementary infrastructure, such as markets, roads and communications is necessary for rural electrification to increase productivity and income. In their study, these authors found that productivity rose 100 to 200 percent, and incomes rose 20 to 70 percent when communities connected to a micro-grid and had such complementary village infrastructure.

Zeyringer, Morawetz, Pachauri, Schmid, and Schmidt (n.d.) posit that the grid power versus decentralized solar PV or generator power decision should be based on the population density, electricity demand and solar irradiation levels. They suggest that when there is high population density, high electricity demand and low solar irradiation the community should have central grid electricity. If the community has low population density, low electricity demand but high solar irradiation levels then the community should rely in decentralized solar PV units. According to these authors, only if all the three factors are low, should the community rely on thermal, fossil generators.

The foregoing studies do not directly discuss the costs of each energy source they analyze. As a result, these authors are unable to comment on the best energy sources for Kenya on a cost base analysis. This paper seeks to fill this gap in the literature.

Specifically, it will examine the cost of electricity sources in Kenya and the physical and economical potential for solar, wind and biomass.

This paper does not propose that cost base should be the sole factor in determining the best energy sources for Kenya. The non-cost factors identified in the existing literature, are important considerations for crafting a comprehensive energy plan. Accordingly, in section 6 several crucial non-cost factors that may be especially important for energy planning in the Kenyan context are identified.

3. Research question

3.1 Background

Kenya was the first African nation to use modern geothermal technology in the 1950s, and due to its unique geography, many renewable energy resources are used and have high potential in the country. The Kenyan government has recognized the potential and benefits of renewable energy, and is continuing to invest in, and foster investment in the renewable energy sector. As discussed above, renewable energy current comprises 68 percent of electricity generation in Kenya. Kenya also recently discovered large economic coal deposits, and some crude oil reserves. Currently, Kenya is beginning to exploit its coal reserves, and intends to use them for power generation. The discovery of coal in Kenya will lead to hard decisions for the government as they attempt to balance economic growth with climate change issues.

Extant energy literature leaves much room for an analysis of the physical and economical potential of solar, wind and biomass for Kenya, as well as a thorough cost analysis of the available energy sources. Thus the goal of this study is to identify the potential for these sources of energy and delve into the associated costs for the eight sources identified. The combination of the two analyses on renewable, fossil and nuclear energy are used to determine the most cost efficient sources. Although the scope of the paper is limited to direct costs, Section 6 presents a brief discussion of some other key issues, such as intermittency and renewables and pollution.

3.2 Research Question

The research question is threefold. Firstly, what is the physical and economic potential for the three electricity source identified? Secondly, of the eight electricity sources identified, what are the most economical sources? And finally, based on this analysis, what are the most abundant and economical sources of electricity generation for Kenya?

To answer this question, I aim to find the physical and economical potential for solar, wind and biomass. I will also perform a per kilowatt hour cost analysis of solar, wind, geothermal, biomass, diesel, gas peaking, nuclear, coal and gas combined cycle.

4. Methodology

4.1 Physical and Economical Potential

The methodology for calculating the physical and economical potential for solar, wind and biomass in Kenya is discussed below. The results are presented in Table 5.1 in section 5. The potential for other sources is not calculated due to a lack of available data.

4.1.1 Solar

The calculation of the electricity potential of solar uses the solar irradiation Kenya receives. The irradiation levels, in kWh/m^2 per day, is given as a yearly average for each 110 km by 110 km block in the data set ranging from 4.78 to 6.77 kWh/m^2/day. The potential for each block is calculated by taking the daily irradiation per meter squared, k, and multiplying it by the number of square meters in each block, n. These are summed to find the total solar power, P_S, Kenya receives on a daily basis: 143.94 GW.

$$P_S = \sum k * n$$

However, not all the power that reaches the country can be converted into energy due to conversion inefficiencies. The calculation must consider the efficiency of a solar technology. This paper considers two solar power technologies: photovoltaic (PV) crystalline and solar thermal tower. PV is a relatively mature technology that absorbs solar irradiation and transforms the heat into electricity through steam generation. This technology has an efficiency, ε_{PV}, ranging from 14 to 16 percent.

$$P_{PV} = \sum k * n * \varepsilon_{PV}$$

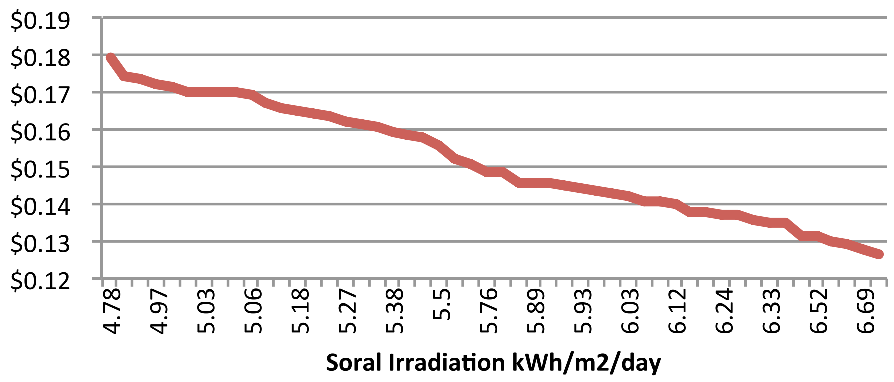
Solar Thermal Tower technology takes advantage of the heat from the sun by focusing it on a single point with mirrors. The focal point, heated by the reflected irradiation, contains molten salt that generates electricity through a steam generator. The average efficiencies of solar thermal, ε_{STh} range from 15 to 22 percent.

$$P_{STh} = \sum k * n * \varepsilon_{STh}$$

The capturable potential in Kenya is calculated by multiplying the total solar irradiation in the country by the efficiency of the technology.[2] The result assumes the physical potential for each technology if the solar plants cover the entire country. Although this is not a realistic possibility, it gives an idea of how much power could theoretically be produced.

To find the more realistic economic potential for the two solar technologies, blocks with irradiation levels below 5.93 kWh/m^2/day are disregarded. This is because the lower irradiation levels in those blocks will lead to a higher per kWh cost as less power can be produced in these areas. Figure 4.1 and Figure 4.2 below shows the cost per square meter, per year, for each block on the x-axis. The average irradiation received in each block is on the y-axis. The graph demonstrates the inverse relationship between solar irradiation and cost.

Figure 4.1:
Crystalline PV LCOE per kWh



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[2] The low end efficiency for each technology is taken to reflect the lowest cost for each technology. Solar technologies with lower efficiencies have lower capital costs. However, the diminished electric return causes longer pay-off times for these technologies.

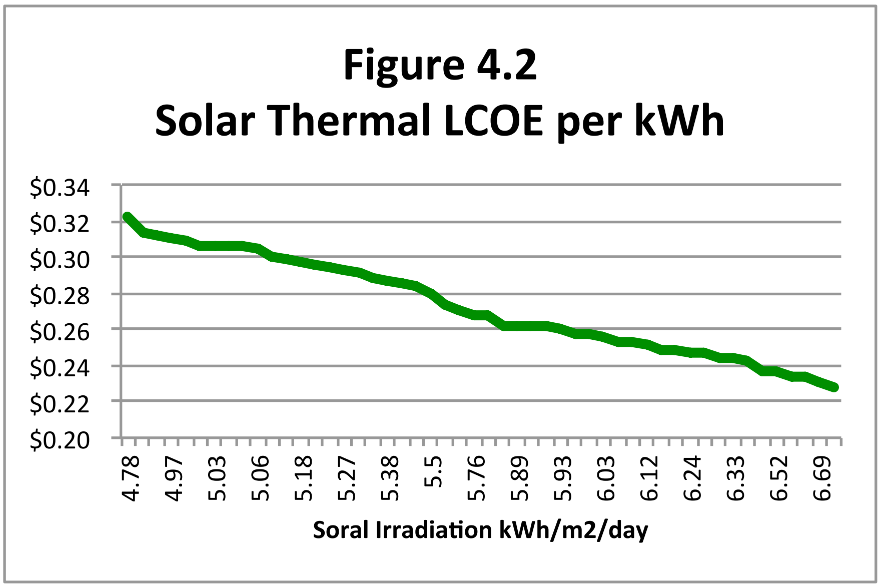

Figure 4.2
Solar Thermal LCOE per kWh

The economic potential is limited to blocks that have a cost per square meter per year below $0.15 for PV and $0.26 for Solar Thermal. This is to ensure only the most profitable sites are used. The potential the remaining 20 blocks is 63.43 GW.

4.1.2 Wind

The potential of wind power calculation uses wind speeds at 50 meters above ground level.[3] Transforming the wind speeds (meters per second) into the wind power (watts per square meter) provides the energy potential of the wind. The formula used is:

$$p_{wind} = \frac{.5 * \rho * \in_{total} * \pi * \left(\frac{d}{2}\right)^2 * v^3}{(5 * d)^2}$$

In this formula ρ is the density of the wind; ε_{total} is the efficiency of the wind turbine; d is the diameter of the rotor blades of the turbine; and, v is the velocity of the wind, or wind speed. The formula shows that the turbine captures only 50 percent of the wind,[4] and the efficiency of the turbine further diminishes the power captured. Thus a turbine with an efficiency of 50 percent would capture only 25 percent of the power in the wind that

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[3] The data used consisted of ground level wind speeds. For the purpose of this analysis, these figures were scaled up using the approach suggested by Oswald *et al.* (2008). Where the Hub Height was 50 meters, Grass height was 0.0002 meters and the Base Height was 1 meter, giving a scaling factor of 1.46.

[4] 50% x 50% = 25%

passes. These calculations assume the lower efficiency because technologies with lower efficiencies have lower capital costs and are thus more attractive for developing countries.

The density of the wind in most parts of the world is one kg per meter cubed, and this is the density used for this paper. The turbine specifications are from the V52 Vestas turbine since the large-scale Lake Turkana wind farm in Kenya uses this model. These turbines have a hub height of 44 meters, are versatile, provide maximum stable power output and cost-effective to transport and install (*Annex A3.3 V52-850 kW, the Turbine that Goes Anywhere.*2005)

The wind power scales from watt per square meter (w/m^2), to kilowatt per square kilometer (kW/km^2) and then transforms to kilowatt-hour per square meter (kWh/km^2). Turbines cannot be placed close together due to the nature of wind; turbines in close proximity *steal* the wind power from one another, thereby diminishing the power that reaches each turbine. The rule of thumb for turbine placement is that the distance between turbines should be five times the diameter of the rotors. I use this distance rule when calculating the wind power potential for the country. This calculation also assumes that wind turbines cover the entire country in order to determine the theoretical maximum capacity. The physical potential is thus approximately 9 terawatts (TW).

This paper identifies the economic potential for wind power by using a cut off wind speed, since only blocks with wind speeds over a certain threshold generate enough wind energy. The wind power available in these blocks is summed and multiplied by the percent of capturable wind, the efficiency of the V52 turbines, and the distance required for each turbine.

4.1.3 Biomass

This paper considers the biomass potential of crop residuals. Although wood fuel is common throughout the country, the household level currently uses it unsustainably. As this paper is concerned with generating electricity, crop residuals are used as a good proxy for the current potential of biomass in Kenya. The crops chosen for the calculations are: maize, rice, tea and wheat. These crops were chosen because of their abundance in Kenya, and the availability of data.[5]

To determine the physical potential for the residuals, this paper adapts the methodology from Nzila, Dewulf, Spanjers, Kiriamiti, and van Langenhovea (2010). In order to find the physical potential for the residuals of the chosen crops, the yearly crop production, *p,* is multiplied by the residue to crop ratio (RPR), dry ratio (DR) and residual energy value (EV).[6]

$$P_B = p * RPR * DR * EV$$

The residue to crop ratio, *RPR,* gives the amount of 'waste' that is produced, e.g. in the case of maize, the leaves and stock of the plant are not used in energy production. The dry ratio, *DR*, gives the amount of dry material to water in the plant. A dry ratio for maize indicates only 15 percent of harvested residuals are available for biomass processing after drying. Finally, the residual energy value, *EV,* is the giga joules (GJ) per ton for each of the crops.

This equation indicates the physical potential if all the residuals are captured and used to produce energy. However, capturing all of the residuals from a harvest is unlikely for two reasons. First, it would be almost impossible for a farmer to gather 100 percent of the residuals left from a harvest, as some will be scattered by the wind and left on the fields. Second, even if it were possible to collect all of the residuals, doing so would harm the quality of the soil by depriving the soil of the nutrients in the residuals. In their study, Fischer, Hiznyik, Prieler, and van Velthuizen (2007) use a collection rate of 50 percent, based on earlier studies, to ensure the soil remains sufficiently enriched to grow future crops.

To find the economic potential for biomass from residuals in Kenya, the collection rate must be included. The efficiency of the power plant must also be considered, as the

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[5] The yearly production in tons data was taken from the FAOSTAT database.

[6] These ratios were taken from Fischer, Hiznyik, Prieler, and van Velthuizen (2007) and Henstock & Hall (1995).

plant will be unable to transform 100 percent of the dry biomass into electricity. Thus in order to find the economic potential for biomass, the total physical potential is multiplied by the collection rate, *CR*, and the efficiency of the plant, ε_B.

$$P_B = p * RPR * DR * EV * CR$$

4.2 Costs of Electricity Generation

The direct cost of electricity generation from each source is calculated using the Levelized Cost of Electricity (LCOE). The LCOE is based on the plant costs, operation and maintenance costs and fuel costs. There are two ways of finding the LCOE, first is the simple method, and the second takes into account the time value of money (TVM LCOE). This section discusses the two LCOE methods and the limitations of the methodology and this paper. The Indirect costs of electricity generation will be discussed section 6 of the paper.

4.2.1 LCOE

The methodology used in this paper to assess the different energy sources is the Levelized Cost of Electricity (LCOE). This method is widely used in the industry as a means of calculating the costs of different electricity sources on a comparable basis (IEA/NEA/OECD 2010). The LCOE of any technology generates a per kilowatt hour cost based on the capital costs, operation and maintenance costs and fuel costs of an electricity source over one year. This allow technologies that are traditionally difficult to compare, comparability on a per unit of electricity basis. Next, there is a discussion of each of the input factors and formulas first for the simple LCOE and the TVM LCOE.

Capital costs (c_p) are all the costs incurred to have the plant up and running. This cost is small when considering installing one solar photovoltaic (PV) unit on a roof, or quite large when building a nuclear reactor. These costs are then transformed to a dollar per kilowatt-hour (kWh) value by using the capital recovery factor (R), the capacity factor (f) and the number of hours in a typical one-year period (H).

$$Capital\ Costs = \left[\frac{R * c_p}{H * f}\right]$$

The recovery factor is the share of plant cost that the revenues must cover each year to recoup all of the capital costs over the lifetime of the plant. It is essential for finding the amount of the capital costs that must be covered in that one-year period because the LCOE is calculated with yearly costs. It is calculated using the discount rate (r) and the economic life of the plant (T).

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

The capacity factor is the power produced in one year divided by the total power produced if the plant was running 100 percent of the time over a year. This is essential for transforming yearly costs into a cost per unit of electricity (kWh). The capacity factor is multiplied by the number of hours in a year to give the total number of hours electricity is produced per year. This figure is then used to find the per kWh cost for the capital costs, operations costs and fuel costs by dividing the yearly cost by the number of hours the plant operates per year (f * H).

The next factor included in the LCOE calculation is the Operation and Maintenance (O&M) costs (c_o). The capacity factor and hours per year transform the one-year costs into dollar per kWh. This calculation also takes into account the increase in costs as the plant ages, through the levelization factor (l). The levelization factor depends on the discount rate (r) for the project and the annual escalation rate for the costs (e).

$$O\&M\ Costs = \left[l * \left(\frac{c_O}{H * f}\right)\right]$$

where,

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

The final component of the LCOE is the fuel costs (c_f). The capacity factor and hours per year transform the one-year costs to a dollar per kWh. The potential of increase in the fuel costs is also taken into account by multiplying the dollar per kWh cost of fuel by the levelization factor. This cost not present for all of the energy sources, most renewable technologies do not require purchased fuel inputs. For example wind, soar irradiation and water are free.

$$Fuel\ Costs = \left[l * \left(\frac{c_f}{H * f}\right)\right]$$

The complete simple LCOE formula when put together is as follows:

$$C_{LCOE} = \left[\frac{R * c_p}{H * f}\right] + \left[l * \left(\frac{c_O}{H * f}\right)\right] + \left[l * \left(\frac{c_f}{H * f}\right)\right]$$

There are two forms of this calculation the simple LCOE and an LCOE calculation that includes the time value of money (TVM) (Timilsina, Cornelis van Kooten, and Narbel 2013). The simple LCOE takes all of the capital investments made to create the plant, and assumes the costs have occurred over night. This limits the result, as the time needed to build the power plants varies from 6 months to 10 years. By not considering timing, capital costs can be overstated, and investment decisions are not fully informed.

The TVM LCOE solves this issue by taking into account the time value of money (TVM) (Timilsina, Cornelis van Kooten, and Narbel 2013). TVM is the theory that a dollar today is worth more than a dollar one year from now due to inflation. Using this concept, it is possible to adjust for the different plant life spans and construction times, as well as the timing of these costs. For example, when comparing a wind farm with a coal plant, the wind farm has initial capital costs, and then negligible operations and management costs over the lifetime of the plant, where as the coal plant has a lower initial investment, but then has fuel costs for the entire life of the plant as well as operation and management costs.

The modified formula is:

$$TMV\,LCOE = \frac{\sum_{i=l}^{k} \frac{OC/_{k}}{(1+r)^{i}} + \sum_{j=k}^{T} \Big(\big(FOM + (VOM * PC * f) + (FC * PC * f)\big) * \big(1 - (1+r)^{-T}\big) \Big)}{(PC * T * f * H)}$$

The first part of the formula looks at the construction costs, (OC), that are levelized over the construction period, (k), so that the cost is the same in each year. The yearly cost is then discounted back to time zero using the discount rate (r) and (k). The second part of the formula looks at the costs incurred over the life of the project, and brings them back to the present. The fixed maintenance costs, *FOM,* given in a dollar per kw-year basis, are added to the yearly variable O&M costs. The yearly variable O&M costs are found by multiplying the variable O&M costs (VOM), given in a dollar per kWh basis, by the plant capacity (PC) and the capacity factor of the plant (f). The yearly O&M costs are then added to the yearly fuel costs, found by multiplying the fuel costs (FC), given in a dollar per kWh basis, by the plant capacity and the capacity factor.

The O&M and fuel costs are assumed to continue in annuity for the life of the plant (T) and are discounted back to present by multiplying by the annuity discount model. The final step is to divide the sum of the plant costs, O&M costs and fuel costs by the amount of power produced over the lifetime of the plant to find the cost per unit of energy. The amount of power produced is the plant capacity multiplied by the life of the plant and the number of producing hours in a year (f* H).

Although the TVM LCOE is able to account for the timing of investments and costs, it is very sensitive to the discount rate used. High discount rates skew the results down, because it unduly minimizes future costs. For the purposes of this paper, both the simple LCOE and TVM LCOE are used. The TVM LCOE takes into account the amount of time it takes to build the plants and the simple LCOE focuses on the differences in costs (Timilsina, Cornelis van Kooten, and Narbel 2013). The timing of investments and construction will play a role in deciding an energy mix, for example, installing a solar PV panel on a rooftop gives access to electricity much faster than constructing a nuclear plant. Although the solar panel may not be a good long-term, solution for energy source for a country the value created by having fast access to power may call for investment.

4.2.2 Assumptions

The LCOE rests on two key assumed values, the discount rate and the escalation rate. As was discussed in the previous section, these two figures are important in the calculation of both the simple and TVM LCOE and can greatly influence the results. Due to the difficulty in finding the 'correct' rates, and to ensure this paper provides a robust result, a sensitivity analysis is done for a high and low scenario. For the high scenario, the discount rate is 10 percent, and the escalation rate is 2 percent. The low scenario uses a discount rate of 5 percent and an escalation rate of 1 percent. These figures were chosen based on the country specific situation and the suggestion made by the IPCC (Core Writing Team, Pachauri, and Reisinger 2007).[7]

4.2.3 Extensions

For this analysis, the LCOE is extended to include a carbon tax. A sensitivity analysis of three different carbon taxes is included in order to find the true cost of electricity. The three carbon tax levels are \$10, \$20 and \$30 per ton of CO_2 equivalent. These three levels were chosen to reflect the carbon tax levels around the world ("Where Carbon is Taxed." 2013)

Although it seems unlikely for Kenya will introduce a carbon tax any time soon, over time the country will need to minimize the amount of carbon emitted. Further, electricity-generating companies may soon be held responsible for the costs of local and global emissions. The carbon tax included in this analysis covers either the future costs of carbon, or the cost of local and global emissions payable by generating companies.

4.2.5 Limitations

This section discusses the limitations of the LCOE model and this thesis. The LCOE framework has some limitations. The simplistic version of the calculation does not take into account the time value of money, and thus treats all costs as happening overnight (IEA/NEA/OECD 2010). By not considering the time value of money or the investment timing into account the costs are overstated. For example, a nuclear plant takes almost

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[7] The 2007 IPCC report suggests a discount rate of 10 to 12 percent for developing countries, and a rate of 4 to 6 for developed countries.

six years to build and costs approximately $8.8 billion. In comparison, a wind turbine takes one year to build and costs $200 million. By using the simple LCOE calculation, the entire infrastructure cost is assumed to happen overnight, and then using the capital recovery ratio, the portion of the total cost that must be recaptured in the first year is included in the LCOE. By comparison, if considering the timing of investment, the construction cost is spread equally over the construction period, and discounted to year 0. The TVM LCOE gives a more realistic basis for comparison, as costs are discounted over time and in a common unit ($/kWh).

The next limitation of the LCOE is that it only includes direct costs in the calculation (Roth and Ambs 2004; IPCC 2011). The costs considered by the LCOE are the capital construction costs, the operation and management costs and the fuel costs. It does not consider the costs of each source, for example environmental damage, intermittency, transmission losses, etc. This paper attempts to include some of these costs by including a carbon tax to help show the costs to the environment. However, this will not completely account for the costs to the environment, nor will it consider the costs to the community or infrastructure. An example of the costs to a community is the loss or gain in property value in the presence of a specific energy source. For example, there is some anecdotal evidence suggesting that in some cases the presence of a wind farm caused property values to drop. However, these costs are hard to quantify and are thus not considered in this paper beyond the introduction of a carbon price. The costs to infrastructure, such as intermittency, location dependency and transmission losses are discussed in section 6.

The third limitation is the sensitivity to the discount and escalation rate estimations (IPCC 2011; Black and Veatch 2011; Steyn 2006; Griffin 2009). The true discount rate and escalation rate are very difficult to forecast accurately at the time of investment and may change over time. To mitigate this limitation, this paper uses a sensitivity analysis by taking a high cost and low cost scenarios, as previously explained. Although this will not perfectly capture the potential variation over the life of the power plants created, the use of the high and low scenario show the impact of the changes on the costs. For the TVM LCOE the discount rate has an even larger impact, and can significantly skew results. For this reason and to ensure robust results, a third, lower discount rate of 0.01 percent is taken in a portion of the analysis.

The limitations of this paper are mainly due to the availability of data. For the physical and economical potential calculations, the available of data for Kenya limit the potentials found. Although the data found for wind was reliable, it was based on ground level wind speeds that were scaled up using a single scaling factor. The scaling factor was based on level grassland surrounding the turbine. Although this simplifying assumption was necessary for the calculations, it is quite unrealistic, and does not take into account Kenya's varied landscape. The actual wind speeds may vary greatly from those used in this paper due to the limited data available. For the biomass calculations, data was only available for some crops produced in Kenya, namely maize, rice, tea and wheat. Other input sources for biomas, such as municipal waste, animal manure and human waste, are also not included due to lack of available data. Thus, the data limitations understate the physical and economic potential for both wind and biomass, and exclude the calculation of potential for the other sources.

A further data limitation apparent in the results of this paper is the costs used to calculate the LCOE. Standard costs were used for the capital and O&M costs, along with the standard heat rates, capacity factors etc. These were taken from the Lazard Levelized Cost of Energy Analysis version 7.0 from August 2013. The fuel costs, however, are from Kenya specific or African sources. The lack of Kenya specific costs for each of the sources limits the results of the analysis.

This paper makes conclusions based on these simplifying assumptions. The costs used are representative of Kenyan costs and thus offer guidelines for investment. Further, this paper attempts to overcome the limitations of the LCOE theory by adding a TVM, carbon tax and sensitivity analyses to ensure robust results.

5. Results

The results of the potential and costs analyses in Kenya are in line with the results of similar studies for Kenya (Kiplagat, Wang, and Li 2011; Nzila et al. 2010; *National Energy Policy.*2012; Mariita 2002; Ogola, Davidsdottir, and Fridleifsson 2012). This paper uses the potential and costs identified to find the most abundant and economical sources of electricity in Kenya. The following sections will present the findings of the analyses carried out for potential and cost of electricity generating sources. A discussion of the benefits and challenges of the four identified sources, and the implication of Kenyan coal follow the results.

5.1 Physical and Economic Potential

Table 5.1 summarizes the physical and economic potential for solar, wind and biomass in Kenya.

Table 5.1

	Physical Potential (GW)	**Economic Potential (GW)**
Solar PV Crystalline[8]	19.36	8.06
Solar Thermal Tower	20.75	8.64
Wind[9]	43.00	17.90
Biomass[10]	0.43	0.19
Total	**83.54**	**34.79**

The technology with the highest economic potential is wind, followed by solar thermal tower and solar PV. However, the data available limits these results. For example, the potential for biomass is based on the 2012 residuals from maize, rice, tea and wheat. Other products grown in Kenya, such as cotton, coffee and cut flowers, would also have the potential to supply residuals for energy production. For example, the Kenya Flower Council found a potential of 10 MW from the waste produced by the industry on a yearly basis (*National Energy Policy.*2012) If all of the agricultural wastes, and other

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[8] The data for solar irradiation levels was taken from the SWERA tool, specifically the NASA Surface Meteorology and Solar Energy (SSE) Release 6.0 Data Set (Jan 2008). "Solar Energy and Wind Resources Assessment (SWERA): Renewable energy data exploration," in United Nations [database online]. [cited 2014]. Available from http://maps.nrel.gov/swera?visible=swera_dni_nasa_lo_res&opacity=50&extent=33.91,-4.67,41.91,4.62.

[9] The data for wind speeds was taken from the SWERA tool, specifically the NASA Surface Meteorology and Solar Energy (SSE) Release 6.0 Data Set (Jan 2008). ibid.

[10] The data for biomass was taken from the World Bank database.

biomass sources could be included in the calculations, it would be significantly higher than the potential found in this analysis.

The potential for other energy sources, such as geothermal, is well documented in the literature. Geothermal has 4 to 7 GW of potential scattered throughout the Great Rift Valley (Kiplagat, Wang, and Li 2011; "Geothermal Development Company." 2014; *National Energy Policy.*2012; Mariita 2002; Ogola, Davidsdottir, and Fridleifsson 2012). Hydropower, although highly utilized still has a large potential of 3 to 6 GW for large hydro projects and 3 GW for small hydro projects (Kiplagat, Wang, and Li 2011; *National Energy Policy.*2012).

Kenya's Vision 2030 has a goal of producing and transmitting 23 GW of electricity ("Vision 2030." 2011). As can be seen, if Kenya was able to harvest the economic potential of the sources analyzed, it would more than meet that goal. Thus the issues surrounding electricity generation in Kenya are related to the infrastructure and cost of building power plants, rather than the availability of energy sources. The next section discusses the results of the cost analysis.

5.2 Electricity Costs

Table 5.2 summarizes the costs of generating electricity based on the simple LCOE. It shows the sensitivity analysis with the high and low interest rates and escalation rates. The carbon tax scenario uses the high estimates, and a carbon tax of $30 per ton of CO_2 equivalent. As is seen the lowest cost in the high scenario and the carbon tax scenario are wind, nuclear, biomass and solar thin-film PV. For the low scenario solar PV and biomass switch positions, as PV becomes slightly cheaper than biomass.

Table 5.2			
	Low Scenario	**High Scenario**	**Carbon Tax ($30)**
Wind	$0.08	$0.11	$0.11
Nuclear	$0.08	$0.12	$0.12
Biomass	$0.11	$0.13	$0.13
PV Thin-film	$0.10	$0.14	$0.14
Geothermal	$0.13	$0.17	$0.17
Gas Combined Cycle	$0.12	$0.14	$5.57
Coal	$0.12	$0.17	$9.96
Solar Thermal	$0.16	$0.27	$0.27
Diesel	$0.42	$0.46	$5.89

The results align well with the physical potential of the analyzed energy sources, with wind as both the least expensive and the most abundant in the country. Biomass and solar, which have also been identified as abundant, are also among the cheapest energy sources. It is interesting to note the large jump in price for the fossil fuel based sources with the introduction of the carbon tax.

Table 5.3 summarizes the results from the TVM LCOE calculations.

Table 5.3			
	Low Scenario	**High Scenario**	**Carbon Tax ($30)**
Wind	$0.04	$0.03	$0.03
Nuclear	$0.02	$0.02	$0.02
Biomass	$0.02	$0.02	$0.02
PV Thin-film	$0.05	$0.05	$0.05
Geothermal	$0.05	$0.04	$0.04
Gas Combined Cycle	$0.02	$0.02	$0.02
Coal	$0.02	$0.02	$0.02
Solar Thermal	$0.06	$0.05	$0.05
Diesel	$0.01	$0.01	$0.01

This table shows that the cheapest sources when looking at the costs through the TVM LCOE are diesel, then coal, gas combined cycle, biomass and nuclear, followed by wind. It is interesting to see that the carbon tax seems to have no impact on the costs.

The difference between the results from simple LCOE and the TVM LCOE is that the TVM LCOE rewards those projects with low initial costs. The TVM LCOE calculation discounts any costs occurring beyond the first year to year one, meaning that costs that occur in the future are worth less in year one. Given a discount rate of 10 percent, the value of 100 dollars given one year from now today is $\frac{\$100}{(1+.10)^1} = \$90.90$. This change in value can be seen as how highly the 100 dollars is valued today versus how it is valued one year from now, i.e. the \$100 in a year is less valuable than \$100 given today. Therefore, in the TVM LCOE the *value* placed on the construction costs at the beginning are higher than the *value* placed on the fuel and O&M costs occurring in the future (Stern 2006). The discount rate shows the value placed on future versus present costs. A high discount rate places less value on future costs, for example, in the previous scenario with a discount rate of 10 percent, $\frac{\$100}{(1+.10)^1} = \$90.90$, but if instead a discount rate of 1 percent is used than the value of \$100 given a year from now today equals \$99.00. This example shows that a higher discount rate values the future less than a lower discount rate (Stern 2006)

This manifests in the Carbon Tax scenario, where the carbon tax does not affect the normal TVM LCOE scenario because the carbon tax happens in the future, and is thus less valued than the construction costs that occur at the beginning. In this way, the projects with lower upfront costs are considered the cheapest, irrelevant of future costs.

To correct for this issue, the LCOE should use a significantly lower discount; using a discount rate of 0.0001, or 0.01 percent changes the picture. Table 5.4 below gives the results for the TVM LCOE with a discount rate of 0.01 percent.

Table 5.4

	Normal Scenario	**Carbon Tax ($30)**
Wind	$0.04	$0.04
Nuclear	$0.03	$0.03
Biomass	$0.03	$0.03
PV Thin-film	$0.05	$0.05
Geothermal	$0.05	$0.05
Gas Combined Cycle	$0.03	$0.65
Coal	$0.03	$0.59
Solar Thermal	$0.06	$0.06
Diesel	$0.06	$0.68

These results show that with a lower discount rate, the rates more closely reflect the simple LCOE calculations, with nuclear, biomass and wind as the most energy sources. With the introduction of a carbon tax the cost for polluting fossil fuels rises significantly, more accurately reflecting the future costs.

In the case of Kenya, the costs of fossil fuels are very unstable, as all petroleum products are imported. The Kenyan Shilling has been very unstable over the last several years, which further destabilizes the costs of imported fossil fuels. Due to this price instability, a low discount rate should be used to ensure that the risk and cost of the future electricity generation is accurately reflected.

Thus, the most economical electricity generating sources are: wind, nuclear, biomass and solar PV. These sources, aside from nuclear, have also been identified as having a large economical potential in the country. Wind, biomass and solar PV also have the advantages of modularity, thus allowing for scaling the power plants up over time as demand and funding increase.

The next section discusses the benefits and challenges of each source. This is followed by a discussion of the implications of the discovery of coal in Kenya on the future electricity generating mix.

6. Discussion

This section discusses the benefits, challenges and current uses of each of the most abundant and economical sources identified: wind, nuclear, biomass and solar PV. Table 6.1 outlines the benefits and challenges of each source. A discussion of each energy source will follow.

Table 6.1

	Benefits	Challenges
Wind	- Modular - Free fuel - Renewable	- Supply driven - Intermittent - Technology limits - Location dependent - Transmission
Nuclear	- Base load - Not location dependent	- Political issues - Waste disposal
Biomass	- Base load - Existing fuel - Not location dependent	- Some emissions - Potential for harm to soil
Solar PV	- Modular - Free fuel - Renewable - Less intermittent	- Supply driven - Intermittent - Location dependent - Transmission

6.1 Wind

Wind is most economical and most abundant electricity source in Kenya. The advantages of using wind power are its' modularity, free fuel and renewable nature. Wind farms are, by design, modular; individual turbines generate power and together make up a wind farm. To scale power production up or down a wind farm can turn on or off a turbine. This is an important feature for a developing country, as it allows the country to invest and build the wind farms slowly, matching demand and funding. For example, the country would be able to invest in a wind farm that will produce 20 MW, with 21 turbines, but build those turbines slowly over 10 years to match demand. If instead the country invested in a coal plant with 20 MW capacity, then plant would be built with this capacity immediately, leaving no room for slow growth, or growth beyond the 20 MW without building an entirely new plant.

The other advantages are the free fuel and renewable nature of wind farms. The free fuel comes in the form of the wind, a secondary solar source. Presently, there is no change for using wind because it is a public good. Free fuel, along with low O&M costs, means that once the initial investment has been covered by electricity sales, the turbines are able to generate income.

The advantage of renewability is twofold. First, there will always be wind available for capture and transformation into power. Second, producing power from wind does not create any GHG emissions and thus does not contribute to climate change. This is important on a global scale as the world begins to de-carbonize to mitigate future climate change. It is also important for Kenya, because it is among the first to suffer the impacts of the changing climate. Although Kenya alone cannot alter the GHG levels and thus the future of the climate, by sourcing most of the electricity and energy from carbon free source the country will not contribute to the problem.

There are also challenges associated with wind power. These challenges are the supply driven nature of the source, intermittency of the source, the location dependency and the costs of transmitting the energy to the users. Each will be discussed in the following section. The concepts of supply driven generation and intermittency are closely linked. When a source is supply driven, and that supply is not constant, the power generated is intermittent. Both solar and wind power production rely on external, renewable fuel sources, the sun and the wind. Weather patterns and natural cycles greatly impact these energy inputs. Coal, on the other hand, uses a controllable input source, and thus power is generated when there are periods of demand. Wind and solar power are considered supply driven because of the reliance on external energy inputs; i.e. power is produced only when the wind is blowing or the solar rays reach the earth, rather than when power is demanded.

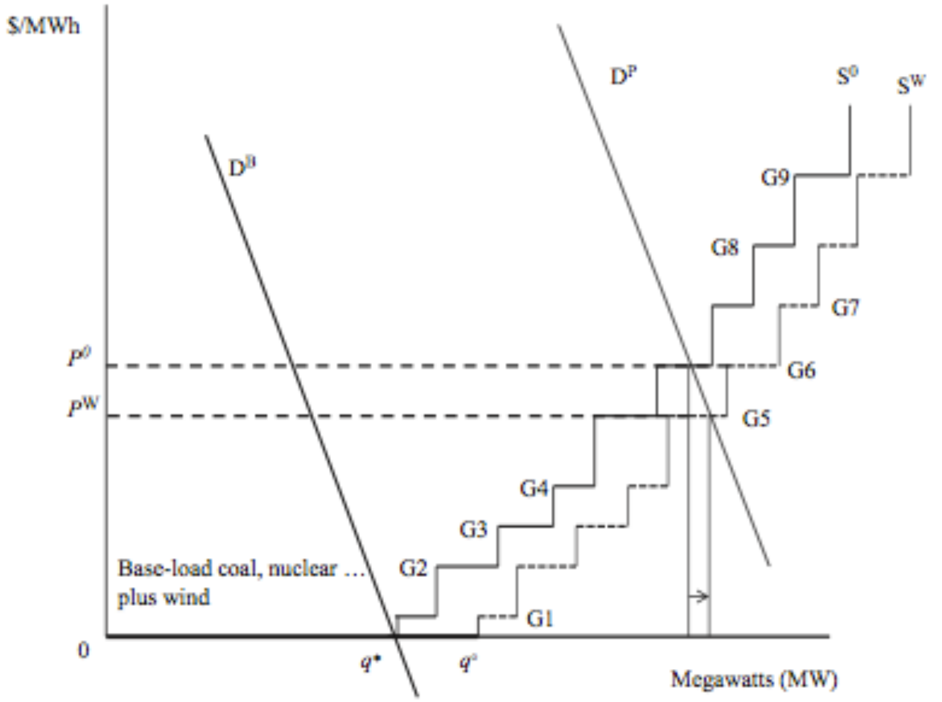
Intermittency is an issue for electricity generation in a number ways. First, intermittent electricity sources are supply driven. For example, in a grid system with only one wind farm if there is no power produced from wind there is no electricity in the system for consumers. However, electricity grids almost never have only one power source and thus when there is no wind, other dispatchable electricity sources (e.g. hydro, fossil fuels) can be turned on/ramped up to ensure consistent supply of energy to the power plant.

The supply driven nature of intermittent sources incurs many costs. Due to the intermittency of wind power there must be back up generating capacity equal to 80 percent of the installed wind capacity (Miskelly 2012). However, these back up plants (frequently thermal fossil fuel plants) are required be on *standby*, meaning that they are producing little power but ready to ramp up power when the wind dies down. This leads to two uneconomical results. First the plants operate below optimal thermal efficiency, requiring more fuel input for the same level of output than would be necessary at optimal efficiency, thus leading to higher fuel prices (Timilsina, Cornelis van Kooten, and Narbel 2013). Further, staying on *standby* may require plants to waste the power they produce while the wind is blowing so as not to over supply the grid. Another option for a grid is to sell any excess power, either from plants on standby or excess wind power, to a neighboring region/country. Selling power to a nearby country then requires that country's' base load thermal plants to ramp down, and operate below optimal efficiency, increasing the fuel costs.

Second, the sudden ramping up of a thermal fossil power plant requires more fuel than if the plant was operating at a constant level, increasing fuel costs. For both of these impacts, the fuel costs of the back-up thermal plants increase on a per energy unit basis, leading to a higher LCOE (Timilsina, Cornelis van Kooten, and Narbel 2013, 642-652).

Another issue created by supply driven power on an electricity grid system is that it leads to inefficient pricing of electricity. In most power systems, electricity is priced using a stepped supply curve, as can be seen in Figure 6.1. Back -up generators will always price their supply at the left end of the supply curve to minimize the fluctuating shut down, start up procedures, which are costly.

Figure 6.1



Source: (Timilsina, Cornelis van Kooten, and Narbel 2013)

However, with the introduction of wind power into the power system, the supply curve shifts right and the price of electricity drops from p0 to pw. This drop in price represents another inefficiency created by wind power. All producers now receive a lower price for their power, while at the same time they are unable operate at optimal efficiency, thus exacerbating the higher fuel costs. This not only makes investing in back up generating capacity less attractive to investors, it causes countries to shift to the cheapest back up generating capacity possible, which is often dirty coal as opposed to relatively cleaner natural gas plants.

Further, intermittent sources are often given government support in the form of Feed in Tariffs (FiT), or subsidies for construction. These make intermittence sources even cheaper than other sources, and encourage investment in, or continued operation of, uneconomical plants. Although subsides are beneficial for helping a technology develop, as in the case of wind in Denmark, developing countries have a focus on increasing energy supply, rather than fostering innovation for a technology. In this way, by not offering subsidies, a developing country is better able to target its goals of increased energy supply, leaving the goal of technology innovations to the energy secure developed world.

There are several methods to mitigate the issues of intermittency: back up generating capacity, techno-spread, geographic dispersion and energy storage capacity (Inhaber 2011; IEA/NEA/OECD 2010). The inefficiencies of back up generating thermal fossil power capacity have previously been discussed. However, if instead of using fossil fuel thermal plants as back up capacity hydropower is used, there is less inefficiency. Hydropower, unlike thermal units, is dispatchable, i.e. it is easily switched on and off and it does not require time or extra fuel to warm up, or significant costs when turned off. The major costs of using hydro are the installation costs and once paid off, there are not significant ongoing costs.

Techno-spread refers to the gains in efficiencies of having a variety of renewable technologies producing power at the same time. The intermittency of different renewable sources is not positively correlated; for example, solar produces power during the day, whereas wind speeds are higher as the sun is going down. Thus the *down time* of one source is covered by the generation from another source. In this way, the techno-spread of a country can create a smoother supply of electricity from renewable sources.

Geographic dispersion is similar to techno-spread, however, rather than having a variety of technologies, it is having a variety of *farms* of each technology around the country/region. The reasoning behind this is that the supply of inputs (wind and solar) will be different around the country, thus the different *farms* will produce power at different times. For example, the wind patterns will not be the same over the entire country, thus by having a few different wind farms the low wind times at one source, will coincide with the higher wind times at another source. In this way, the electricity supply of a country will be smoother by spreading out the sources.

The last way to mitigate the issues of intermittency discussed is energy storage capacity. This allows for smoother consumption of the power produced, by storing the excessive power produced and offering it when there is little power being produced. For example, storing some of the solar energy produced during the day and selling it at night. Concentrated Solar Power (CSP) offers the potential of storage relatively cheaply in large installations, by storing some of the heated material (i.e. molten salt) power can be produced for several hours after sunset (Rawlins and Ashcroft 2013). Another source of storage is pumped-hydro, in which the excess power pumps water up to a reservoir, which can then generate power when needed by the grid.

The third challenge for wind is the limits of the technology. Turbines are only able to produce electricity on average when wind speeds are between 4 meters/second and 15 meters/second, which greatly limit the period during which turbines are able to produce power. Very low and high wind periods produce no power. This makes this source more sensitive to weather than solar.

The fourth challenge for wind is that it is location specific. Since wind power is dependent on wind speed, wind farms are built where wind speeds are high. This can lead to difficulties for transmission lines, as often wind rich areas are not near the main urban areas, and thus the power travels long distances to get to the consumers. Transferring power over long distances leads to power losses and high costs. Currently Kenya loses 14.5 percent of electricity through transmission and distribution (*National Energy Policy.*2012). Upgrading the technology and transmission lines mitigate these losses. However, while the government plans to perform some upgrades, the priority is to increase access to electricity by extending the national grid to more communities, rather than on refurbishing all of the old transmission lines (*National Energy Policy.*2012). When building new wind farms in remote, high wind, areas planners must consider the substantial cost of building the transmission lines to the grid.

The fifth challenge for wind power relates to the previous challenges of intermittency and cost of transmission and distribution. The challenge is the existing is the transmission capacity and the requirements of a grid for intermittent electricity sources. As was mentioned earlier, wind is an intermittent power source, meaning that power is not produced and put on the grid steadily or in predictable patterns. In order to accommodate this variable power, the transmission lines must both be strong and have a large capacity. In order to ensure that sudden spikes of power do not cause the transmission lines to overload, the existing transmission lines should be replaced with newer, stronger lines. However, this will have a significant cost, and as mentioned earlier Kenya's focus is on increasing access to electricity, rather than on shoring up the old transmission lines.

In 2011, Kenya had an installed capacity of 5.45 MW; since then capacity has increased. For example, the Lake Turkana project that will be commissioned this year will have an installed capacity of 300 MW (*National Energy Policy.*2012). The main challenges Kenya is facing are the high upfront costs, long distances from windy areas to grid centers, inadequate data, limited expertise, technological change and competing land use. The government is responding to these challenges by increasing institutional, regulatory and local capacity to promote wind power; promote hybrid power stations (wind-diesel); shore up regulations and incentive programs; and invest in R&D and transmission lines. The government plans to have installed capacity of 3000 MW by 2030 as a part of its Vision 2030 goals (*National Energy Policy.*2012).

6.2 Nuclear Energy

There are many benefits and challenges in the introduction of nuclear power into any country. Nuclear power can provide a stable base load power for the electricity grid, and is not location dependent. Base load power is the electricity generated to meet the minimum electricity demand at all times, and is the foundation of a sound electrical supply system. Currently Kenya is using a mix of hydropower, geothermal and diesel generators for base power. Although these sources can provide stable base load power, there are some issues with each source. In the past Kenya had periods of little to no hydropower electricity generation, due to droughts and insufficiently stocked reservoirs. As was discussed earlier, the introduction of diesel generators occurred because of the droughts in the late 1990s. However, since Kenya has no oil reserves, it is required to import the diesel fuel. Geothermal does provide both stable and renewable base load power, however, the costs of installing the power plants is quite high compared to nuclear power.

As energy demand continues to grow in Kenya, it will be important to have a mix of base load power generators to ensure energy security and sustainability. The mix should include sources, such as nuclear, that require a fuel input to hedge against a changing natural environment, such that geothermal or hydro are no longer able to supply sufficient power to the grid.

The second benefit of nuclear power is that it is not location dependent. Unlike wind, the nuclear power plant can be built closer to consumers, and will therefore have less issue with the transmission and distribution of power. This will lead to lower costs, i.e. not building long transmission lines, and less power losses, i.e. power lost in transmission is proportional to the distance traveled.

The challenges that a country faces when implementing nuclear power plants are significant, especially for developing countries. The challenges are the safety of the technology for the public and the world, the political nature of nuclear power and the disposal of nuclear waste in the future. However, with good planning and sound policies it is possible for developing countries to build and maintain nuclear power plants.

The issues of safety and security for the home country and the world are that potential for nuclear waste to be transformed into nuclear weapons. This is especially an issue for developing countries; for example, in the case of Iran the world has put numerous sanctions to stop the waste enrichment process in the country. Not all developing countries have faced the same challenges as Iran, through robust procedures, policies and safety programs a country can operate nuclear power plants with minimal problems.

The second challenge is the political nature of nuclear power. Generating nuclear electricity has recently fallen out of favor in many countries, in the wake of the Fukushima accident. Although reactors are very safe, and safer technologies are available including reactors that cannot melt down, politicians are hesitant to be pro-nuclear because it is such a highly charged issue. This is mainly due to the lack of education about the use of nuclear power and its dangers (Stone 2013). News organizations often promote the idea that nuclear power plants are dangerous, while those in academia and the industry have the benefit of respected research and have found that nuclear technology is very safe. In order to mitigate this challenge Kenya has invested a lot in nuclear energy research and development. Kenya should continue to invest in research and educational campaigns, both to ensure, and promote the safety of nuclear power plants.

The last challenge is the issue of storing the nuclear waste created by the generator. The waste must be stored for many years under very strict conditions, in order to keep the population safe. This adds significantly to the costs of the technology, if included in the LCOE calculations. For the purposes of this paper, these costs are not included in the LCOE. However, with technological progress, the fourth generation reactors will use the waste from second and third generation reactors as fuel. Further, the waste from the fourth generation reactors is much safer and is stored for a significantly shorter time (Stone 2013). Over time, fourth generation reactors will replace older technology and nuclear waste will no longer be an issue.

Kenya has established a plan for integrating nuclear power in a safe and cost effective manner into the electricity mix. The government established the Nuclear Electricity Project Committee (NEPC) and is developing the sector in accordance with the International Atomic Energy Agency (IAEA) guidelines. Kenya sees nuclear energy as a safe, renewable resource, with a high potential to provide base load electricity generation, and meet the power needs of the increasingly electrified population (*National Energy Policy.*2012).

The government has done extensive research into the nuclear industry to ensure the safety of the proposed nuclear plants. Some of the actions the government is taking to ensure the safety of the plants is: introducing comprehensive nuclear laws, regulations and treaties; and ensuring public awareness, proper training and safety standards. Further, Kenya will employ the most modern, fourth generation reactor technology that cannot melt down. Finally, Kenya will only use small and medium sized reactors (SMRs) in order to ensure the flexibility of the system, lower upfront costs, reduce obligations for waste management and give greater assurance to the international community for non-proliferation of the nuclear waste into weapons (*National Energy Policy.*2012).

In order to meet all regulations and take the necessary steps to ensure a secure environment for nuclear power plants, the government will not commission its first nuclear reactors until 2022, with an installed capacity of 2000 MW. According to the Vision 2030 plans, Kenya would like to source 4000 MW of power from Nuclear by 2030 (*National Energy Policy.*2012)

6.3 Biomass

Biomass is the third, or fourth cheapest electricity source, depending on the calculation method used, and has a large potential in Kenya. Increasing sustainable biomass in Kenya has many advantages, specifically its use as base load power and there are abundant, unexploited fuel sources. Biomass also has little location dependency. Biomass, like nuclear, is a good source of base load power because it is based on an abundant fuel source and can provide the minimum power demand at all times. By combining biomass with nuclear and geothermal, Kenya would have a sustainable and green base load power mix.

The second advantage of biomass is that there is an existing, unexploited fuel source. Kenya has a large agricultural economy, with many large industries such as tea, coffee and cut flowers. The agricultural industry only sells a portion of the total harvested crop, for example in the cut flower industry, only 20 percent of the harvested product is sold on, leaving 80 percent of the harvested crop for other uses (*National Energy Policy.*2012). This large base of unexploited fuel is a great resource for Kenya's power generation.

Other fuel sources, such as animal manure, urban waste and fuel crops, also are abundantly available and largely unexploited in Kenya. However, these sources were not considered in the physical potential calculations due to lack of data (Kiplagat, Wang, and Li 2011). Although, some of these products, such as manure, are currently used, these resources are still largely unexploited. Further, there are studies on bio-fuel crops that could be grown in conjunction with utility sized solar plants or wind farms in arid areas. The solar panels or wind turbines would provide sufficient shade and moisture to grow certain fuel crops in abundance. These crops could then be made into bio-fuels, which in turn could lower the oil imports for Kenya.

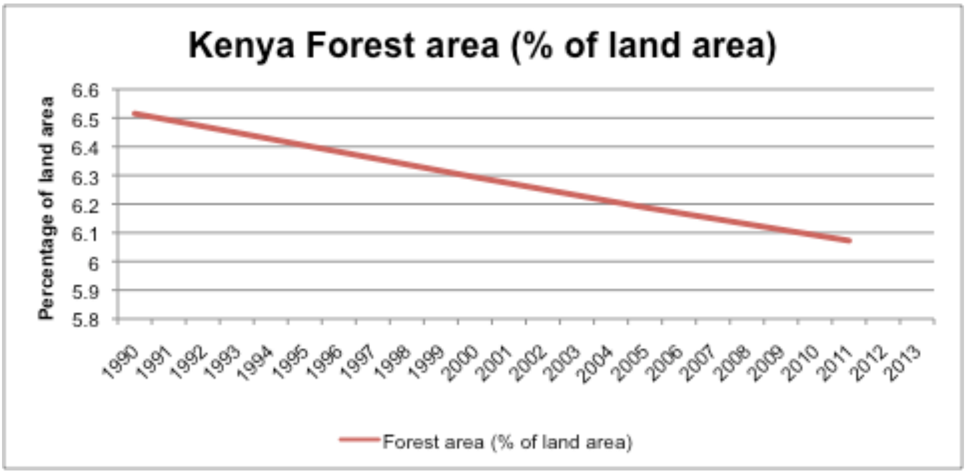
The final advantage of biomass is that it is not location dependent. The fuel for biomass generators can be moved across the country to the power plants. Although there may be some advantages to having the power plants close to the fuel sources, the fuel can be transported. Further the wide variety of fuel sources ensures that power plants would be close to a source.

The challenges of using biomass are that some emit GHG and the potential for decreasing the quality of the soil. Depending on the way the biomass is proses, i.e. biogases, bio-fuel, or biomass burning, there can be some GHG emissions. However, the replanting of the biomass or bio-fuel sources mitigates this concern. The second challenge is the potential damage to farmer's fields by harvesting all of the residuals. As was discussed in the methodology, to maintain nutrient rich soil farmers should harvest only 50 percent of crop residuals.

6.3.1 Biomass

Biomass is the most important source of primary energy in Kenya, with woody biomass as the most common source. The country is experiencing a problem of a growing gap between supply and demand, with a high percentage of the wood taken unsustainably (Kiplagat, Wang, and Li 2011). Due to lack of resource management and the large percentage of poor in the nation, the number of people dependent on wood as a fuel source is remaining constant, despite promotion of alternative fuel sources. Figure 6.2 below shows the steady decline in forest coverage in Kenya over the last 30 years due to poor resource management.

Figure 6.2



Source: ("The World Bank DataBank." 2014)

The problems with woody biomass do not end with poor resource management; pollution, health hazards and lack of knowledge, awareness and data about the resource pose challenges for the government. To combat these issues the government plans to increase data collection; create a central wood resource management plan; increase information and incentives for alternate power generation; and implement health and safety measures within households (*National Energy Policy.*2012).

6.3.2 Bio-fuel

Bio-fuel is currently not a major source of energy in Kenya, however, due to the unique properties of the fuel, the government has set up projects to take advantage of this resource. Unlike other renewable energy sources, bio-fuel is liquid and making it interchangeable with fossil fuels in the transportation industry. Kenya is currently developing the technologies and allocating land, to create blended ethanol-gasoline for the transportation industry (*National Energy Policy.*2012)

Due to the infancy of this industry, the government is facing the challenges of lack of data, information and structures (*National Energy Policy.*2012). However, another unique challenge of biomass, -fuel and –gas is the competition for land use. The use of these energy sources can easily create a choice between a nations food and energy security. Kenya must do adequate research and put policies in place to ensure there is minimal overlap between these two important industries.

One potential source of feedstock is yellow oleander plant that grows in arid areas (Kiplagat, Wang, and Li 2011). This plant is well suited to the arid areas, and has a high potential for creating biofuels. Using this plant would ensure that there was no competition for land between food and energy needs.

6.3.3 Biogas

Biogas has enormous electricity generation potential from sources such as slaughterhouse remnants, municipal waste and agri-waste. Currently Kenya has some pilot biogas projects, using solid waste, manure and banana leaves. Further, in the large cut flower industry, 80 percent of the harvested crop is waste. The government estimates that roughly 200 kWh/ton could be generated daily, with 87 GWh/year generated throughout the country from the cut flower industry alone. (*National Energy Policy.*2012).

The government has become involved with the ‘Biogas for Better Life’[11] initiative that ‘*offers business opportunities as well as improved livelihood and aims at providing two million households in Africa digesters by 2020… it is possible to construct 6 500 biogas digesters in Kenya every 5 years.’* (*National Energy Policy.*2012). The main challenges in taking advantage of this resource are lack of information about the technology; lack of R&D; high upfront costs; lack of skilled workers for installation and operation and maintenance; and lack of regulation for contactors. The government is implementing plans to make the industry more attractive and increase awareness of the potential of this technology (*National Energy Policy.*2012). By 2030 the government plans to have facilitated the construction of at least 10 000 bio-digesters in Kenya under the ‘Biogas for Better Life’ program.

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[11] The African Initiative started the ‘Biogas for Better Life’ program.

6.4 Solar

The advantages and challenges of solar are much the same as for wind. Solar PV is modular, allowing for easy scaling up and down of power production through adding or taking away units. Solar power also has no fuel cost, and is a renewable source thus leading to lower costs throughout the life of the plant.

The challenges facing solar power implementation are intermittency, location dependency and transmission issues. However, solar PV is less susceptible than wind power to all challenges. Solar PV is able to produce power all day when the sun is up, even when it is cloudy. In this way, there is less intermittency and thus less of a strain on the transmission lines and capacity. Solar is also less susceptible to location dependency, solar plants can be installed in most areas in Kenya, because the entire country has high solar irradiation levels. This cuts down on the issue of building lengthy, expensive transmission lines, and losses in power through transmission.

Solar energy is currently widely used for drying goods such as coffee, fish and cereals as well as for water heating and electricity generation through PV systems (*National Energy Policy.*2012). In 2009, the Energy (Solar Water Heating) Regulations came into effect, spurring growth of Solar Water Heating (SWH) installations. Growth for the SHW is projected to be 20 percent annually from 2009 to 2020, raising the number of installed units to over 800 000, equivalent to 300 000 TOE. (*National Energy Policy.*2012).

Throughout the country, there are small scale, off grid solar PV installations. As a part of the REC, the roofs of homes, medical facilities and educational institutions have low cost, low capacity PV units installed on them. The government projects have an installed capacity of PV to reach 10 MW equivalent (MWe) by 2020, generating an average of 22 GWh per year (*National Energy Policy.*2012). Many of the new installations are combination plants of solar wind or solar diesel, because of problems with intermittency. Further, many of the diesel-fired plants are converting to combined solar/diesel plants to improve the carbon impact.

The challenges facing the PV industry are: fragmented regulatory and policy efforts by the government leading to loss of consumer confidence; high cost systems; rampant theft of the PV panels; and lack of financing sources. The government is dealing with these issues by enhancing communication of solar benefits and policies, creating a more enticing investment environment and facilitating the installation of the various technologies. By 2030 the government plans to install 300 000 home PV units, 700 000 SWH units and 500MW of electricity from solar (*National Energy Policy.*2012).

6.5 Coal

According to the Kenyan government, coal is a key energy source of the future ("Vision 2030." 2011). Currently coal is used only in the cement manufacturing industry, and constitutes less than one percent of the primary energy mix (*National Energy Policy.*2012).

The recently discovered coal reserves in the Mui Basin in Kitui County are broken into four blocks for exploration and exploitation. In 2010, Block C was confirmed to contain four hundred million tons, ranging from lignite to sub-bituminous quality with calorific values ranging from 16 to 27 mega joules per kilogram (MJ/kg) (*National Energy Policy.*2012). Due to the large reserves found, the Kenyan government plans to develop 2400 MW of electricity from coal by 2030.

However, due to the recent nature of the coal discoveries, there are many challenges that Kenya will face in developing this sector. The lack of expertise in coal drilling; poor infrastructure: lack of interest by major coal exploration companies due to lack of adequate data: and the nonexistence of legal, fiscal and regulatory frameworks all pose significant challenges for the government. The government plans to tackle these challenges through promotion and mobilization of exploratory drilling; enhancing technical expertise and infrastructure to facilitate coal development; and to encourage market adaptation and integration to ensure industry growth. (*National Energy Policy.*2012).

The government is planning to invest mainly in Clean Coal Technologies (CCT) to mitigate the costs of local pollution and mitigate the GHG output of each plant. When using the simple LCOE calculation, coal is the fifth most economical electricity source, after wind, nuclear, solar PV and biomass, but just slightly ahead of geothermal. However, when using the TVM LCOE coal is on par with biomass, nuclear and combined gas cycle. These figures show that even without a carbon tax, coal is not the most economical energy source. Coal is the most expensive source in the high carbon tax ($30) scenario.

Kenya has historically had one of the greenest energy mixes in the world, due in large part to its natural resources excluding fossil fuels. Now that Kenya has access to coal, it will be interesting to see if the country becomes more carbon intensive. Although it would be better for the country in the long run to avoid high carbon energy sources, due to climate change issues, it will be hard in the short run for Kenya to leave it's coal in the ground. Currently Kenya has very limited access to electricity, and what access is available is unstable and is subject to blackouts.

As was discussed earlier, there is a relationship between electricity and energy consumption with economic growth. Kenya, through its Vision 2030, aims to develop economically at a rapid pace over the next 25 years ("Vision 2030." 2011). This development will require a huge supply of energy, and the country will exploit the most economical sources of energy first ("Vision 2030." 2011). Depending on the calculations made, and the policies in place, coal maybe identified as one of the most economical sources. Although exploiting coal on a large scale may cause the country to become carbon intensive, if it is able to help lift its population out of poverty it is hard to advise against it.

One option that would both keep carbon emissions low and allow Kenya to fully exploit its coal reserves, would be to use only the most modern and environmentally friendly technologies for energy production from coal. Modern CCT reduces emissions and thus could be a suitable option for Kenya to use its coal reserves in the most environmentally friendly way. However, this technology costs more and are thus less likely to be built by the country seeking low cost energy sources, or at the very least will not be exploited first.

If Kenya puts an explicit or implicit price on carbon, then it is much more likely that CCT will be used, as the savings on the carbon emissions would cover the higher capital costs. A carbon price would also discourage the country from relying too heavily on coal, as it will seek to exploit more economical energy sources first. These more economical sources are all renewable technologies plus nuclear. However, it is currently unlikely that Kenya would put a tax on carbon; the country's focus is on helping to foster economic growth, rather than on ensuring a renewable energy mix. Although increasing carbon emissions may be detrimental in the long run due to climate change, if using these energy sources will help pull the country out of poverty, it may be seen as a good trade-off for the government.

7. Conclusion

This thesis aimed to find the most abundant and economical energy sources in Kenya, using various techniques to find the physical and economical potential and costs. The LCOE is extended to include the timing of investments and a carbon tax. These extensions, along with a sensitivity analysis for the discount and escalation rates, offer robust results.

Wind, nuclear, biomass and solar PV are the most economical and abundant electricity sources for Kenya. The country is currently creating policies and industries to foster the growth of these resources, and in the case of nuclear, make it possible for the industry to develop and flourish. Each of these technologies poses challenges. For example, wind and solar technologies are supply driven, intermittent and not dispatchable. This puts strains on the power grid, and requires either substantial storage facilities available or back up generating power to fill in the power lags. However, using a combination of these four sources mitigate the challenges posed by individual sources. In this way, alongside existing energy infrastructure, Kenya would be able to power its future at the lowest cost.

Kenya’s recent discovery of coal may cause the country to move away from its historically renewable energy mix, towards a more carbon intensive one. However, the exploration of coal could be minimal depending on the measures used and the price of carbon. If Kenya does decide to exploit its coal reserves for electricity generation, the country should use only Clean Coal Technologies, as these will minimize the amount of carbon emitted. Although Kenya has not historically been a large GHG emitter, it has already begun to feel the effects of climate change, most notably the severe droughts of 2000.

Further research using Kenya specific data, and with a focus on the future of coal as an energy source in the country would be interesting. It would also be interesting to do further research on the policies that Kenya could use to shape its energy future.

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