Institute of Water and Energy Sciences (Including Climate Change)

UTILIZING A MULTI-CRITERIA DECISION MAKING APPROACH TO EVALUATE SUSTAINABILITY OF RENEWABLE ENERGY GENERATION SOURCES IN UGANDA.

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Date: 04/09/2017

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Academic Year: 2016-2017

This research thesis is submitted in partial fulfillment of the requirements of Masters of Science in Energy Engineering at Pan African University Institute of Water and Energy Sciences (including Climate Change)-(PAUWES) at the University of Tlemcen in Algeria.

August 2017.

DECLARATION

I, **Cleus Bamutura**, hereby declare that this thesis is my original work and to the best of my knowledge, it has not been submitted for any award in any University or Institution.

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CERTIFICATION

This thesis has been submitted with my approval as the supervisor

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ABSTRACT

There are increasing concerns on utilization of energy resources ranging from perceived economic, technical, environmental and socio political risks in the deployment of renewable energy systems which affects the suitability and sustainability relating to usage the alternative renewable energy sources for energy generation. This research assesses the various generation sources in Uganda based on a multi criteria decision making approach to determine the most suitable energy resource alternative. This is done by utilizing Analytical Hierarchy Approach which enables a pairwise comparison of the criteria in relation to the goal, sub criteria in respect to the parent criteria and finally the energy generation sources to the various criteria to come up with a ranking of renewable energy generation sources in the order of priority.

Uganda has hydro power potential of about 2,200 MW, Solar Energy potential of about 200MW, Bioenergy potential of 1650MW, Geothermal Energy of 450MW, and wind speeds ranging between 3-5 M/s. This generation potential is sufficient to meet Uganda's current energy needs.

The research shows that environmental and technical criteria are the most important criteria with respect to the goal with a score of 39.44% and 31.91% respectively followed by social political 22.56% and the least being economic criteria scoring 6.09%. This implies that prioritization of renewable energy deployment is majorly hinged on these two fundamental aspects.

Weight of sub-criteria in comparison with the parent criteria reveals that the most important aspects operation and maintenance cost at 36% for economic criteria technological maturity at 38.3% for technical criteria, emission reduction at 73.1% for environmental criteria and job creation at 73.1% for socio political criteria. This implies that in renewable energy deployment, high consideration of these sub criteria should be taken compared to other sub criteria. The comparison of renewable energy generation source alternatives indicate that solar energy is the leading option with respect to economic criterion at 32.4%, hydropower as the leading option at 22.7% with respect to technical criteria, solar as the leading generation source at 22.7% with respect to environmental criterion and hydro-power as leading with 54.3% with respect to socio political criterion. The priority ranking of the renewable energy generation sources indicates that hydro power is the first alternative generation source at 27.0% followed by solar power at 22.1% and 15.9% 14.2 %, 8.1% for wind, geothermal and biomass energy respectively.

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NOMENCLATURE

MCDM	Multi-Criteria Decision Making
MEMD	Ministry of Energy and Mineral Development
AHP	Analytical Hierarchy Approach
RE	Renewable Energy
RETs	Renewable Energy Technologies
WENRECO	West Nile Rural Electrification Company
MW	Mega Watt
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
REA	Rural Electrification Agency

CHAPTER ONE

1 INTRODUCTION

1.1 Background information

Globally, energy consumption has increased significantly over the last decades due to social economic development needs with fossil fuels dominating the energy sector (Ohunakin, 2010). Fossil fuels have diverse impacts on the environment including air pollution, acid rain and greenhouse gas emissions in addition to their finite nature and thus it's inevitable that the world needs to find renewable alternative sources of energy such as solar, wind, bioenergy solar-hydrogen among other forms of energy. Technological developments have been taking place in the past decade making renewable technologies more important with solar and wind currently playing a major role worldwide (Sen, 1997). Fossil fuels have deemed the current energy trends unsustainable and thus the global goals targeting access to clean and secure energy for the people to strike a balance between energy security, environmental protection and economic development that guarantees a secure future for the next generations(Fyrippis I, Axaopoulos PJ, 2010). National energy policies have a very important role to play in terms of building and sustaining power equilibrium with increasing importance of energy in national development(Ozturk, 2017). Thus prioritization and development of local energy generation sources will increasingly become important to guarantee energy sufficiency and security.

Renewable energy sources have potential to contribute to sustainable energy development in various countries and enhance environmental, social and economic benefits. Renewable energy constitutes about 28% of the global energy generation capacity and has increasingly become a good option to provide innovative and sustainable solutions to meet the future energy needs for the growing global population (ISRES, 2017). The increasing demand for electricity has created an opportunity for innovative generation solutions in distributed generation systems to increase access to energy. The awareness of the public about climate change and environmental impacts resulting from energy generation have also created interest in renewable energy (Al-maghalseh & Maharmeh, 2016). A number of countries have renewable share in electricity production of about 20% and by 2012 the share of RE had increased by 8.5% compared to 2011. By the end of 2012 the leading countries in RE were China, United States of America, Brazil, Canada and Germany.

The increase in concern for the environmental cost on the environment caused by utilization of fossil fuels has also made renewable energy a realistic alternative for energy production (Engstrom, 2017). There are however still a number of challenges pertaining the deployment of renewable energy such as economics for production and although technologies such as nuclear are largely contested for safety reasons and fossil fuels contested for pollution, there is still a challenge of allocating funds for renewable energy as long as it has not been proved as a feasible option for power production in economic terms as economics remains a dominating factor in politicians' benefit evaluations (Engstrom, 2017).

The energy sector in Uganda is under the mandate of the Ministry for Energy and Mineral Development (MEMD) and guided by policies and associated legislations in energy, minerals, oil and gas such as the Energy Policy 2002, Renewable Energy Policy 2007, among other statutory instruments (MEMD, 2013). The government of the republic of Uganda spelt out her commitment to develop renewable energy for sustainable development in the 2002 National energy policy. Consequently, to re-emphasize government in development of RE, the renewable energy policy 2007 with at 10-year plan to meet the target of 61 percent from 4% share in 2007 (MEMD, 2007).

Uganda has considerable renewable energy resources for energy production and the provision of energy services, yet they remain unexploited, largely due to the perceived technical and financial risks. These resources include: biomass, geothermal, large scale hydro, mini/micro/pico hydro, wind and solar energy. However, with the exception of biomass, whose contribution is very significant, the remaining renewable sources (including large hydro), contribute about 5% of the country's total energy consumption(ERA, 2013a).

Table 1-1: Renewable Energy Resource Potential in Uganda (Source: Renewable energy Policy of Uganda, 2007)

Renewable Energy Potential	
Source	Potential in MW
Hydro	2,000
Mini-Hydro	200
Solar	200
Biomass	1,650
Geothermal	450
Peat	800
Wind	
Total	5,300

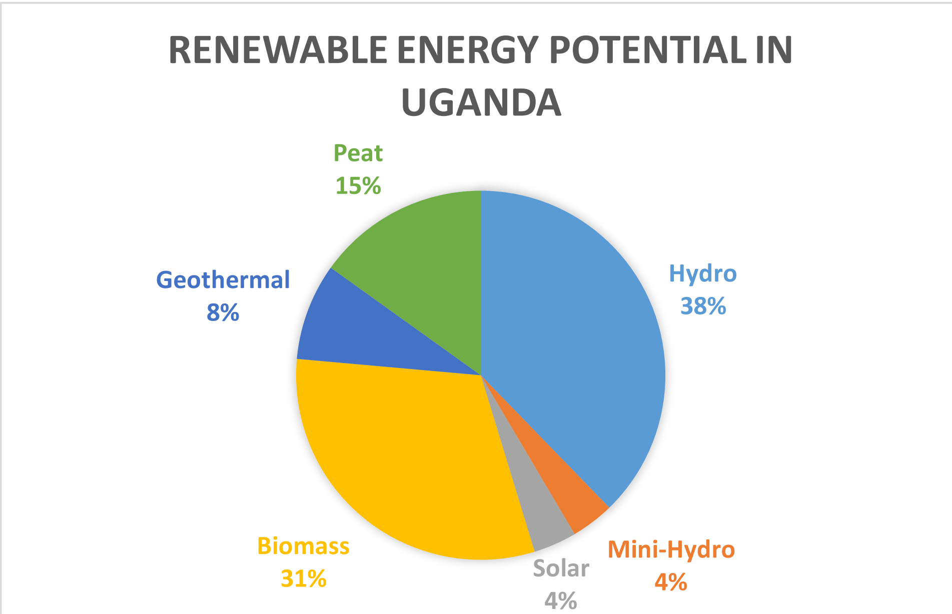

Figure 1-1: Renewable Energy Potential in Uganda, Share from each source. (Data Source: Renewable Energy Policy for Uganda, 2007)

Uganda's electricity is mainly from hydro power stations Nalubaale (Owen falls Dam), Bujagali and Kiira Power along the river Nile. This is in addition to various thermal plants, mini and micro hydro stations scattered over the country which are either grid connected or independent power stations supplying power to particular communities (UBOS, 2014). These include Kihihi, Kisiizi Hospital thermal power, and the West Nile Rural Electrification Company (WENRECO) among others. Thermal power plants from bagasse such as Kakira also supply electricity to the grid. Uganda still imports electricity from Rwanda and as well exports some of the generated power to neighboring countries: Rwanda, Kenya and Tanzania (UBOS, 2014). There was an increase in the total installed capacity of electricity power plants by about 1.2% from 885 MW in 2014 to 895.5 MW in 2015. This resulted from 19.4% increase in bagasse fired plant capacity from 54 MW in 2014 to 64.5 MW in 2015 (UBOS, 2016a).

Table 1-2: Installed capacity of Renewable Energy in Uganda by Source (Ministry of Energy and Mineral Development of Uganda Report, 2015)

Source	Thermal	Large-Hydro	Small-Hydro	Solar	Biomass	Hybrid
Installed capacity (MW)	135	635	64.8	20	88.5	1.6

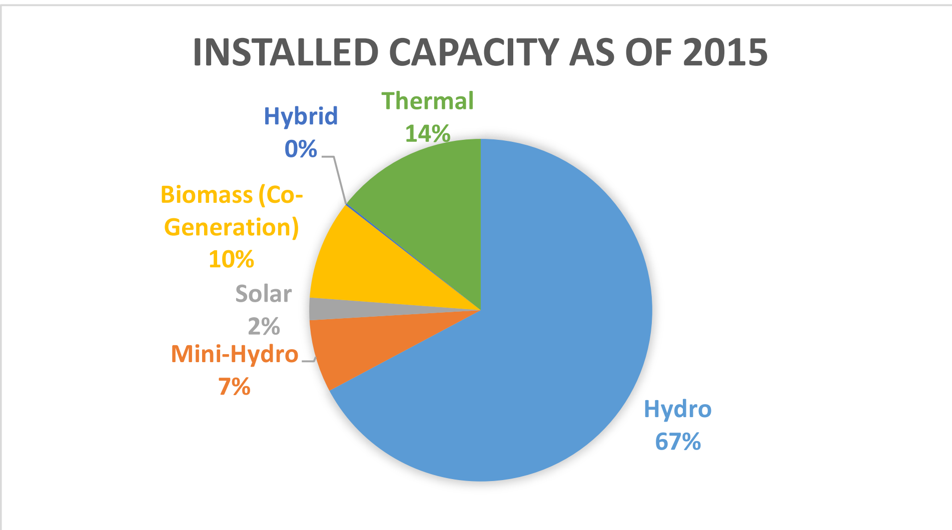

Figure 1-2: Installed capacity of renewable energy in Uganda, percentage contribution from each generation source

Renewable energy already plays an important role in Uganda's current generation mix with hydro power providing about 67% of the electrical power generation. According to MEMD (2015) thermal plants are also still important providing about 14% of the energy generation in the country (MEMD, 2015).

1.2 Statement of the problem

Consumers are increasingly critical and include sustainability in their purchase decisions. Environmental, societal and economic issues have thus become increasingly part of decision criteria for consumers of a range of products ranging including energy and other services. Whereas the major cause of global changes in climate are largely attributed to anthropogenic carbon emission of which utilization of energy from burning of fossil fuels i.e. oil, coal and natural gas are highly important (Pollin, 2017). Zimmerman (2017) notes that energy efficiency and renewable energy deployment need not suffer from association with climate change mitigation but rather work with people's situations to improve their lives(Zimmerman & Zimmerman, 2017). This implies that renewable energy focus should rather be related to sustainably dealing with people's needs for energy rather than being only tagged to climate change. Governments, developers and financial institutions need to thus be conscious of the investment decisions they take in energy systems by considering sustainability issues as part and partial of their decision-making criteria if the energy systems are to satisfy people's needs.

Kammerl (2017) notes that sustainability is a very complex issue that may cause some companies and institutions not to make consideration of sustainability in their activities. He further states that developing frameworks are the first steps towards making this complex task tangible, projectable and accessible. Moreover, methods and tolls utilized require additional capital and time in many cases which makes it more difficult to apply those approaches. The motivation is also mainly based on government and legislative incentives, conditions and benefits. Most such as life cycle assessment (LCA) are applied at later stages of the projects because they require a large information base which makes it difficult to include some sustainability aspects and the process very expensive.

Financing for renewable energy projects has been challenging for a long time. These are projects that have potential to benefit society and stimulate economic activity. However due to high risk associated with renewable energy many financial institutions offer high interest rates. Thus, many of the renewable energy projects are either financed by government or donations as social projects. This hinders potential investment in these projects which could potentially work as tangible business.

This study will utilize Analytical Hierarchy Approach (AHP) multi-criteria decision making approach to evaluate the most suitable renewable energy generation source for Uganda. The approach will consider technical, socio-political, economic and environmental aspects of sustainability to enable decision making in financing for renewable energy at both business and government level and build confidence in promotion of financing for the renewable energy projects.

1.3 Study justification

Sustainable energy development is a critical factor for sustainable economic development. Operational frameworks to harness energy resources for human use and boost lasting development are thus key factors to consider if the countries resources are to be developed without jeopardizing the needs of the future generations.

According to Munasinghe (2013) energy has emerged as a key resource which critically interacts with key aspects of sustainability such has the economy, environment and social wellbeing (Munasinghe, 2013). Energy has underpinned economic development and in turn economic progress stimulates energy demand. Increased demand for energy has significant impact on the environment especially energy from conventional fossil fuels and yet increased access to energy can significantly improve the social wellbeing of the people. this research will be relevant in providing a way forward on priority to invest in renewable energy to tackle the challenge of energy access, energy security as well as deal head on with the unprecedented global challenge of climate change while taking into consideration the various interlinkages between energy and sustainable development.

1.4 Objectives

General objective

To provide a benchmark for prioritization of renewable energy sources in Uganda.

Specific objectives:

Specific secondary research objectives are formulated to enable achievement of the primary research objectives. They include the following:

- To assess renewable energy resources availability in Uganda
- To create a criteria and sub-criteria for decision making
- To provide a framework for decision making for renewable energy technology deployment
- To make recommendations to market participants in renewable energy on sustainable deployment for renewable energy

1.5 Research question

Which renewable energy resource should be prioritized for investment in Uganda?

1.6 Hypothesis

Evaluation of technical, socio-political, economic, and environmental aspects of renewable energy power generation sources using the Analytical Hierarchy Approach (AHP) provides hydro-power as the first alternative renewable energy generation source in Uganda.

1.7 Scope of the study

The study assesses renewable energy generation sources using Analytical Hierarchy Approach to determine the most sustainable generation source for Uganda. Data about generation sources is obtained from available records and online sources, categorized and analyzed. Deductions are made from the outputs of the assessment criteria.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Renewable energy potential in Uganda

Uganda has a variety of renewable energy sources such as biomass, solar, wind, hydro, geothermal, among others. Traditional biomass contributes more than 90% of Uganda's primary energy and about 80% of electricity is produced from hydro power plants. Present RE energy use accounts for about 1% of total primary energy use and about 17% if traditional biomass is not included(UBOS, 2016a). Uganda thus has enormous potential for renewable energy that is not yet tapped. The various forms of renewable energy including biomass, hydro power, solar energy, geothermal, are discussed below.

According to UNBS (2016) energy purchases increased by 4% from 3,203 GWh in 2014 to 3,335 GWh in 2015 while the number of UMEME customers increased by 21.9% from 667,483 to 813,402 in 2015 with the total number of power plants increasing by 1.2%. this implies that the need for electricity far exceeds the increase in energy generation in Uganda (UNBS, 2016).

Energy consumption is an important component of industrial economy and prosperity of people (Rafique, 2017). Uganda has a number of potential renewable energy generation sources ranging from hydropower, solar, geothermal, biomass, wind among others from which to generate necessary energy to meet the population needs.

However, priority must be given to the most sustainable resources in order to guarantee gains from the generation sources. A review of various energy generation sources is discussed below.

2.1.1 Bio-energy

Biomass

Primary energy supply in Uganda is dominated by biomass (wood, charcoal & agricultural residues) contributing about 90% of primary energy demand and accounting for about 6% of the country's (MEMD, 2014a) . It's more important in villages where it acts as both a source of energy and income.

Biomass is any organic matter that is available on a renewable basis mainly through photosynthesis. In the energy context, biomass means products consisting of any whole or part of a vegetable matter from agriculture or forestry, which can be used as a fuel for the purpose of recovering its energy content (MEMD, 2014a). Biomass includes firewood, shrubs, grasses, forest wastes and agro-industrial residues. Examples are bagasse, husks, trash from sugar, oil milling, grain milling, etc.

The demand for woody biomass is currently estimated at 44million tons per year. Available forest cover can only provide for 26 million tons (WWF, 2015). This implies that at the current rate of demand, there is likely to be high levels of deforestation and thus there is need to find more sustainable clean energies to counter this environmental concern. In addition, Uganda consumes about 1.8 million tons of charcoal per annum derived from about 16 million of wood (MEMD, 2014b). According to WWF (2015)(WWF, 2015), Uganda was said to be losing about 1.8% of forest cover per year and an estimated 47% of forest cover had been lost between 1990 and 2010 according to MEMD (2014)(MEMD, 2014a) as of 2013 and thus it's important to protect the remaining 2.6 million hectares of forest cover which is approximately 11% of the total land mass.

Total potential for electricity generation from biomass in Uganda is estimated at about 1650

MW. The total potential for cogeneration in Uganda is currently estimated at 190 MW (Asere, 2014). Currently Cogeneration from bagasse produces 50 MW at Kakira Sugar Works, 14.5 MW

from Kinyara Sugar Works and 11.9 MW from Sugar and Allied Industries Kaliro (UBOS, 2016a). this potential is likely to continue increasing with increase in agro-processing and value

addition to agricultural products.

The figure 2-1 shows biomass distribution in Uganda.

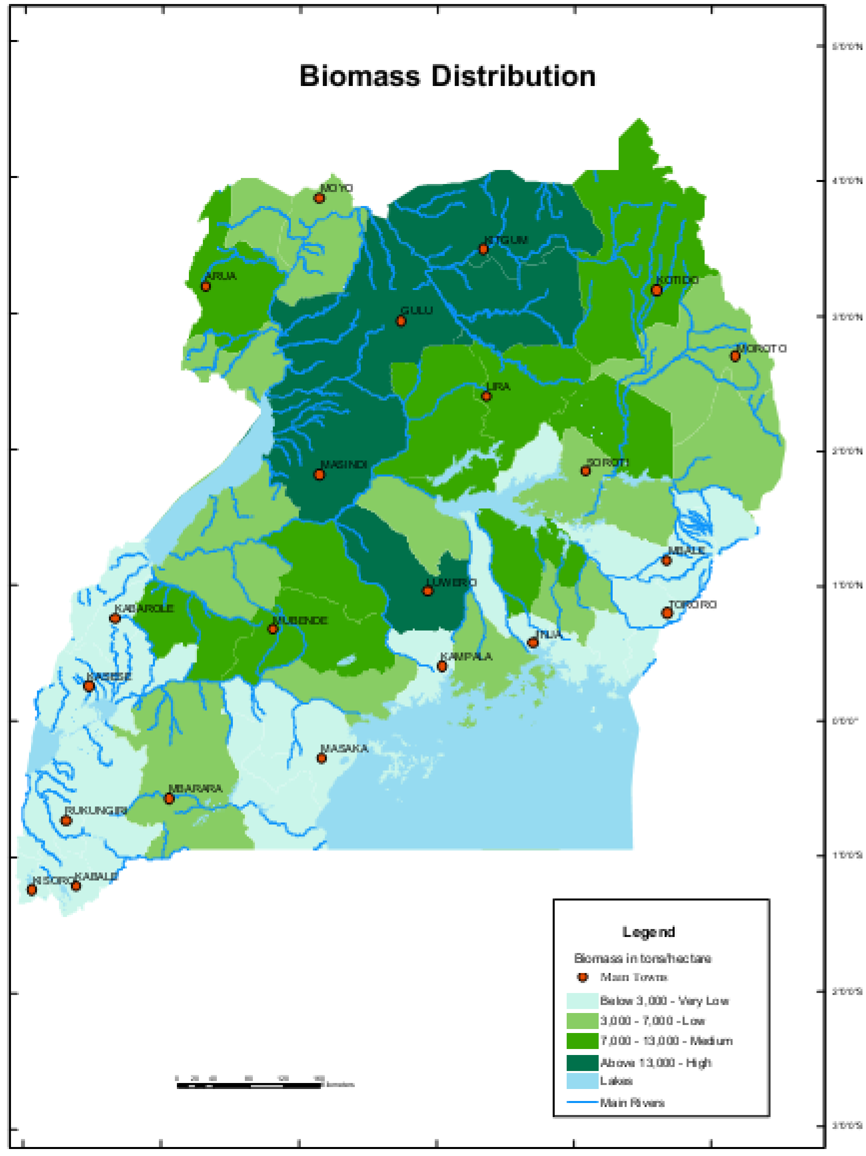

Figure 2-1: Biomass Distribution in Uganda (Source: Renewable Energy Policy 2007)

Biogas

Biogas is 55-70% methane (CH_4) with varying amounts of carbon dioxide (CO_2) as the chief constituents. It also has traces of hydrogen sulphide (H_2S), ammonia (NH_3), oxygen, hydrogen (H_2) and water vapour (H_2O), depending upon feed materials and other conditions. The feed materials are usually animal and human waste. Biogas is a zero-waste technology. The products of biogas plants, like biogas and digested slurry, can be utilized economically for cooking and as manure for agriculture and horticulture (REA, 2007). Currently about 5000 units of family sized Biogas have been installed under National Domestic biogas program (SNV, 2014). There is potential to increase biogas for home steads especially in the cattle corridors in Uganda which have a lot of animal and other agricultural waste.

Bio fuels

In Uganda, ethanol is being produced on a small scale by sugar manufacturers as a by-product from the molasses and several small cottage industries from cereals and fruits (REA, 2007).
It is estimated that in the year 2010 Uganda will import and consume 360 million litres of diesel and 385 million litres of gasoline. If this fuel could be blended with environmentally friendly locally produced biofuel, Methyl Alcohol (25% for gasoline and 60% diesel), it would require a total of 312 million litres of Methyl Alcohol, a product from timber locally grown by the rural population. In terms of impact on environment, if a total of 312 million litres of petroleum products are replaced by Methyl Alcohol, this will replace nearly one million tons of CO2 emission in the country (REA, 2007). This would thus reduce the environmental problems associated with carbon emissions. According to the renewable energy policy 2007, blending 5 mandates for Uganda were supposed to be established to enable utilization of biofuel as alternative source of fuel especially for transport (MEMD, 2007).

2.1.2 Hydro-Power

Uganda has high hydro power potential with the Nile alone estimated at about 2,000 MW including six potential major hydropower sites: Bujagali 250 MW, Kalagala 450MW, Karuma (Kamdini) 150 MW, Ayago North 300 MW, Ayago South 250 MW and Murchison Falls 600 MW. Bujagali and Karuma sites have been significantly studied and are being developed on a Public Private Partnership (PPP) basis to generate electricity in the medium term (REA, 2007). Installed capacity of small scale hydro is slightly over 65 MW (REA, 2007). Some of the small-scale Hydro-power stations include Bugoye 13 MW, Mpanga 18 MW, and Nyagak 3.5 MW (ERA, 2013a).

Figure 2-2 shows potential sites for large hydro power generation sources

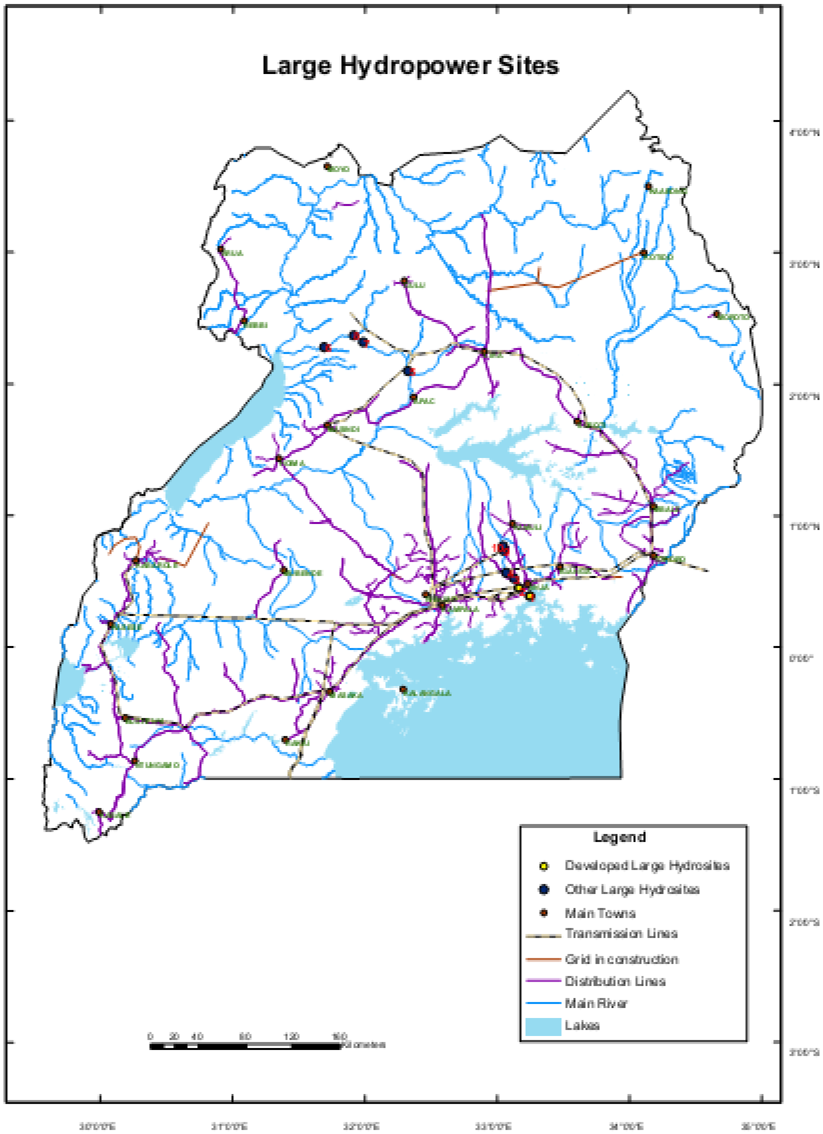

Figure 2-2: Large Hydro-power sites in Uganda (Source; Renewable Energy Policy 2007)

Figure 2-3 shows locations with mini hydro generation sources. It should be noted that mini hydro power stations can act as potential for mini grids and would be essential in promoting livelihood of the persons around it. This significantly reduces the cost of transportation or otherwise.

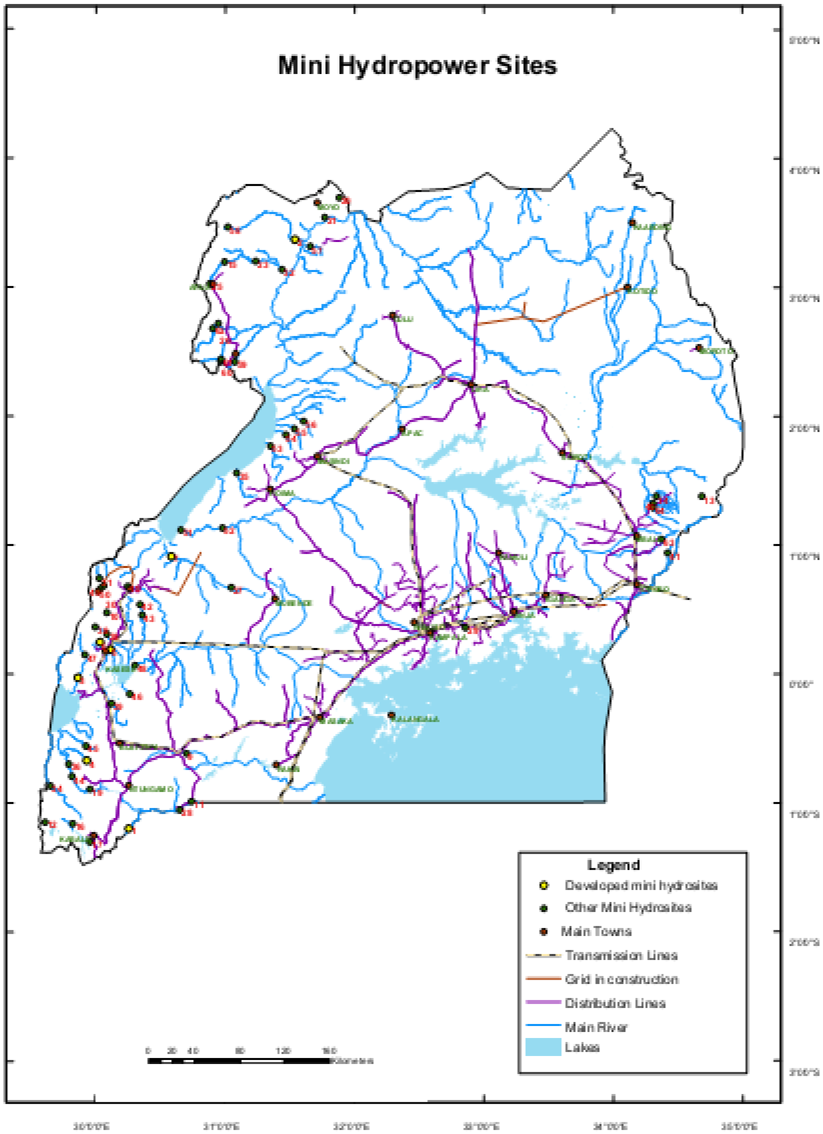

Figure 2-3: Mini Hydro Power Sites (Source: Renewable Energy Policy 2007)

2.1.3 Solar energy Potential

Existing solar data clearly show that the solar energy resource in Uganda is high throughout the year. The mean solar radiation is 5.1 kWh/m2 per day, on a horizontal surface. This level of insolation is quite favorable, for the application of solar technologies such as solar water heating and solar photovoltaic systems for supply of basic electricity in rural institutions and households as well as areas not connected to the grid (REA, 2007). Solar thermal has a great potential in the form of solar water heaters in electrified areas. By 2012, solar PV systems had been installed 5,600 households, 420 small commercial, and 1700 institutions through schemes initiated by Rural

Electrification Agency (REA) and other donor agencies, (MEMD, 2012). Today electricity is most often used for water heating, in spite of the fact that it will in many cases be cheaper for the consumer to use solar energy. Figure 2-4 shows solar availability in Uganda.

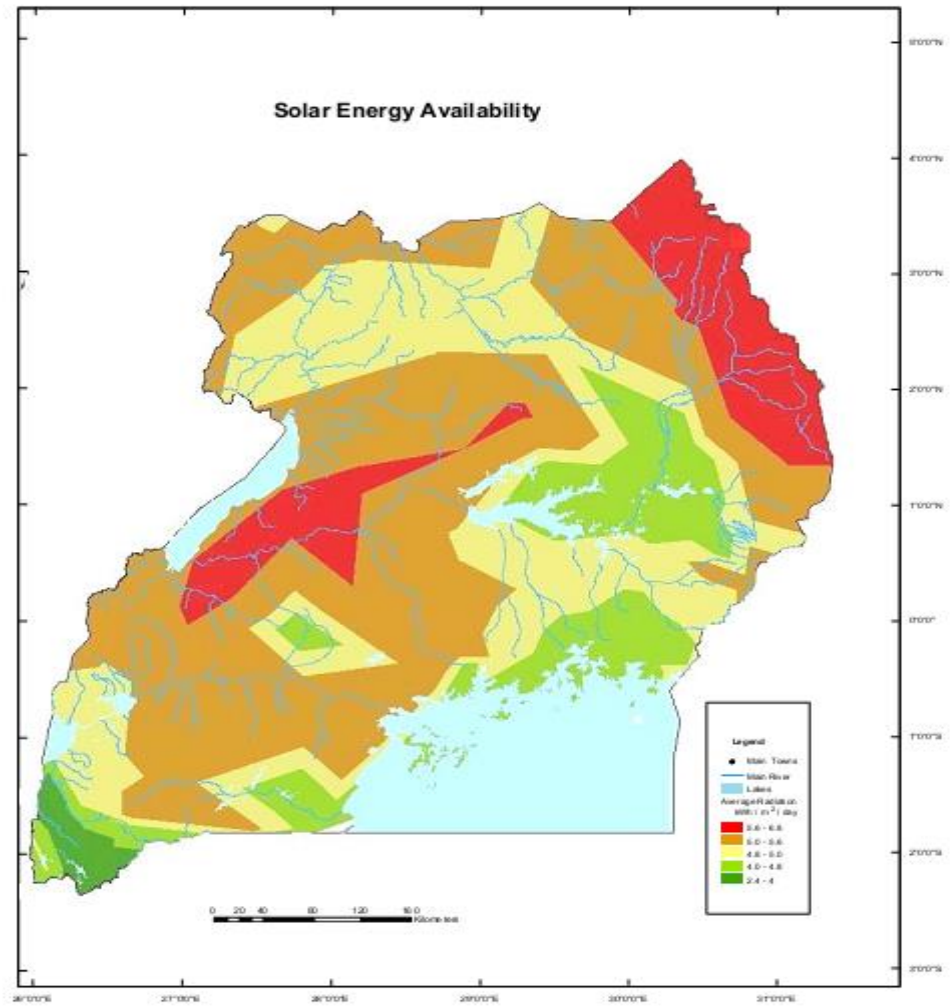

Figure 2-4: Solar map for Uganda showing solar availability(Source: Renewable Energy Policy 2007)

Off-grid and On-grid solar PV

The market for off grid systems mostly businesses privately owned, pico and home solar systems has steadily grown within the last fifteen years reaching 1.1MW as of 2012 and still growing at a rate of 20%. With players like M-Kopa, solar lanterns have been widely spread through the Pay-As Go system in the country. Through the Rural Electrification Program approximately 7720 systems were installed in households, small commercials and institutions like schools, police etc. (WWF, 2015).

Uganda's solar irradiation ranges from 1'825 KWh/m2 to 2,500 KWh/m2 per year. Two large solar PV plants are at planning stage and the government has plans to build 500 MW capacity whose implementation has been awarded to Ergon Solair a Taiwan-US partnership. A 10 MW PV power plant has been developed in Soroti and is the first PV project to benefit from the GETFiT programme (EUEI PDF, 2017). Below is the solar map for Uganda.

2.1.4 Geothermal

Geothermal energy is one of the possible alternative renewable energy sources in Uganda, which will supplement other sources of energy. Its major advantages are that it is environmentally friendly and multidisciplinary in uses, since it can support various development activities ranging from production to processing of raw materials, like minerals and agricultural produce. Three major potential sites namely Katwe-Kikorongo (Kasese), Buranga (Bundibugyo), and Kibiro (Hoima) were identified with a combined geothermal potential of 450MW (REA, 2007). Despite the high geothermal potential, no single plant has been constructed.

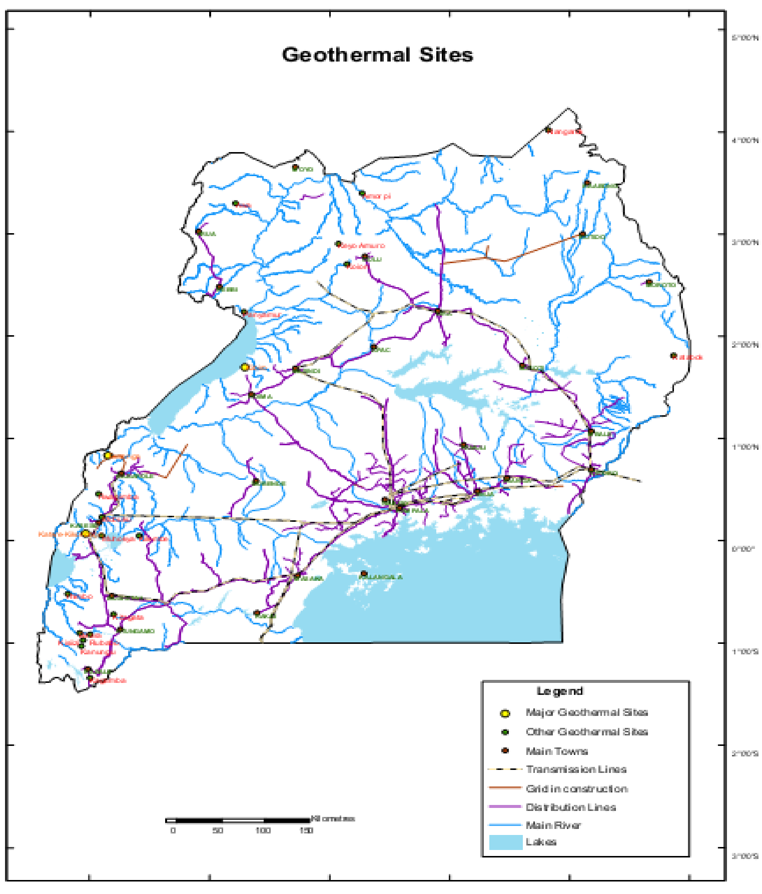

Figure 2-5: Geothermal Sites in Uganda (Source: Renewable Energy Policy 2007)

2.1.5 Wind energy

Wind potential in Uganda is low because of low wind speeds. The wind speeds in Uganda range for 2-4m/s. Based on wind data collected by the Meteorology Department, it was concluded that the wind energy resource in Uganda, is sufficient for small scale electricity generation and for special applications, such as water pumping mainly in the Karamoja region (REA, 2007). The areas with demonstrated high wind potential in Uganda are limited. Area such as Nebbi, Tororo, Gulu, Apac, Moyo, Moroto and Kotido could demonstrate high potential for energy production from wind with advancement in technology (WWF, 2015). Below is figure 2-6 showing wind availability in Uganda.

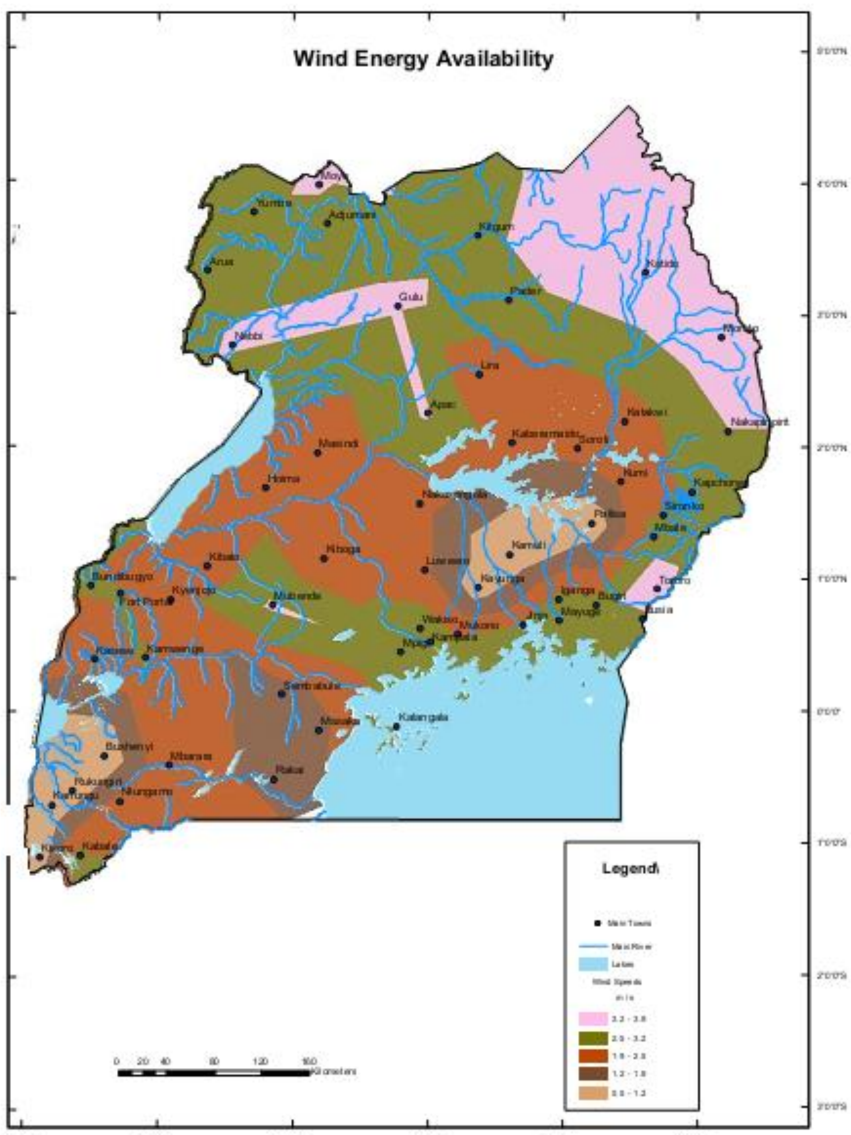

Figure 2-6: Map showing wind availability in Uganda (Source: Renewable Energy Policy 2007)

2.2 Conventional energy resources

2.2.1 Petroleum Resources

Out the total primary energy supply of Uganda, 9.2% is met by petroleum products (Broad, Hankins, Mathias, & Karin, 2015). By 2015, the total installed capacity of electricity was 895.5MW (UBOS, 2016b). The installed thermal power plants capacity has gradually decreased from 170MW in 2011 to 136MW in 2015 due to continuous decommissioning and replacement by hydro power plants (BAANABE, 2012)(UBOS, 2016b). Those currently in operation include; Electromax that increased its capacity from 20MW in 2011 to 86MW in 2015 and Jacobsen plant – Namanve with 50MW installed capacity (UBOS, 2016b). Uganda's crude oil potential is estimated to be 6.5 million barrels of oil reserves with 1.4 billion barrels estimated to be recoverable while the gas in place stands at 461BCF (MEMD, 2013). All these reserves are located in the Albertine Graben region in Western Uganda. These are yet to be exploited. Therefore, currently all the petroleum products used in the country are imported (Broad et al., 2015). If this country's resource is to be exploited for production and exportation, it's estimated to last for only 30 years (Broad et al., 2015). Uganda being a landlocked country, all these products are routed through Kenya and Tanzania in the ratio of 17 to 3 respectively. This puts Uganda at a stake of depending on the political stability of her neighbors for supply in addition to incurring high transportation costs through these seaports of Mombasa and Dar-es Salaam. Due to the above reasons, Uganda has now finished with its plans of constructing a 10-12 inch diameter 1450km pipeline through Tanzania(Tumwesigye, Twebaze, Makuregye, & Muyambi, 2011). In 2015, Uganda imported 1.622 billion litres of petroleum products (UBOS, 2016b). On a daily basis the country imports roughly 7000 barrels of oil per day from Kenya's Mombasa oil refinery which also imports the crude oil from abroad (Tumwesigye et al., 2011).

The oil and gas industry employs 1028, 2364 and 6784 people directly, indirectly and induced according to the report of ministry of energy and mineral development of Uganda in 2013 (MEMD, 2013).

Petroleum fuels used in Uganda are mainly diesel, petrol, Kerosene and to a limited extent liquefied petroleum gas. These are mainly used for transportation, on and off grid power production, lighting and cooking. Transportation accounts for the biggest fossil fuel consumption. Approximately 75% of the fossil fuel import bill is for the sector (Tumwesigye et al., 2011).

2.2.2 Peat

A theoretical volume of approximately 250 million oil equivalent tonnes is available in Uganda(Government, 2007). However, due to its existence mostly in wetlands and its varying quality, this makes it impossible to exploit using conventional methods due to the strict wetland policy. Therefore, only 10% of the total potential can be used for production of power through other methods. The available peat resource volume if exploited would translate into 800MW for the next 50 years(ERA, 2013b). The resource is widely dispersed mostly in the western and south western parts of Uganda. According to (ERA, 2013b), Kabale Energy Limited was authorized to undertake studies for the generation of an equivalent of 33MW using peat resource in the district of Kabale.

2.3 Implications of fossil fuel exploitation on deployment of renewable energy in Uganda

Finding of exploitable amounts of oil at commercial level in Uganda marked an on and off exploration of the resource in Uganda. This has attracted many international companies and business corporations in the oil sector to the country to kick start development of the oil sector. As of 2014, an estimated 6.5 billion barrels of oil had been discovered with about 1.8-2.2 recoverable reserves at present time. The production is expected to reach heights between 200,000 and 250,000 barrels per day based on the current discoveries which places Uganda among the present middle African producers such as Equatorial Guinea and Gabon (Kathman & Shannon, 2011). A pipe line will be constructed from Uganda via Tanzania to serve the international, thus implies the need for Uganda to put in place clear regulatory framework together with the regional members in order to benefit from this recent discovery.

The exploitation of petroleum in Uganda will create competition for the renewable energy in Uganda and will likely delay deployment of some of the new energy technologies considering the cost of utilizing fossil fuel is low compared to cleanest energy technologies that are present currently.

2.4 Energy policy perspective and institutional frame works

The energy sector in the republic of Uganda is under the mandate of the ministry of energy and mineral development of the republic of Uganda. In the renewable energy policy of 2007, Government of the republic of Uganda created a renewable energy department at the ministry of energy and mineral development and established a national committee and several committees at local government level to promote sustainable use of renewable energies in Uganda (MEMD, 2007). This department is mandated to implement the renewable energy policy targets as set out in the relevant RE policies and programmes.

The Energy policy 2002 of Uganda was put in place in 2002 with a main goal of meeting Uganda's energy needs in the most economical, socially and environmentally sustainable manner possible (MEMD, 2002). This emphasized the need to develop Uganda's energy sources both renewable and non-renewable for sustainable development.

The National Oil and Gas Policy for Uganda was put in place in 2008 with a major policy goal to use the country's oil and gas resources to contribute to early achievement of poverty eradication and create lasting value to society (MEMD, 2008). Apart from creating a conducive environment for petroleum exploration to continue in the country and the anticipated development, production and utilization of any discovered resources to take place, the policy also seeks to put in place a framework for the efficient management of the oil and gas resources as well as revenues accruing therefrom.

2.5 Renewable Energy Policy 2007

In 2007 government put in a place the renewable energy policy with an Overall Government Policy Vision for the role of Renewable Energy in the national energy economy as: "To make modern renewable energy a substantial part of the national energy consumption".

The Overall Renewable Energy Policy Goal as: "To increase the use of modern renewable energy, from the current 4% to 61% of the total energy consumption by the year 2017" (MEMD, 2007).

This policy put in place strategies among which were: Credit Support Facility and Smart Subsidies which are intended to scale up investments in renewable energy and rural electrification and establishment of the National Environmental Management Authority (NEMA) (REA, 2007). This was meant to answer the question of accessibility and also create favorable environment for penetration of renewable energy technologies whilst addressing the global environmental concerns.

2.6 The future of renewable energies in Uganda

The Uganda renewable energy scenario presents a viable model in which modern energy services, based on currently available technology, are accessible to all. It explores how Uganda can stimulate a growing economy based on renewable energy instead of venturing down a business-as-usual path with increased dependency on fossil fuels. It also recognizes that to be sustainable, the renewable energy solutions presented must have limited negative impact on biodiversity, ecosystems and climate (WWF, 2015). In the energy mix projection given below it is expected that by 2050 Uganda will be majorly depending on renewable energies mainly hydro, solar and geothermal with the rest of the supply being catered for by the other sources including fossil fuels.

2.7 Renewable Support Mechanisms in Uganda

Several African Countries in Africa have implemented renewable energy support policies and mechanisms and Uganda has been part and partial of the move to improve energy needs by putting in place the frameworks below in abid to achieve energy sufficiency for the people of Uganda. According to IRENA (2015) (IRENA, 2015a) Uganda has in place the following mechanisms to fast track renewable energy deployment.

1. Feed in tariff (including premium payment)
2. Capital subsidy, grant or rebate
3. Reduction in sales, CO_2, VAT or other taxes
4. Public investment, loans or grants

These mechanisms are essential for renewable deployment, prioritization of the most suitable renewable energy resources would thus act as a supportive mechanism and enhance the gains of the various policy mechanisms that are already in place to support renewable energy deployment.

2.8 Renewable Energy Power Generation Costs

Renewable energy has become increasingly competitive with a range of generation technologies. Renewables have thus not only witnessed economic and technological progress but have rather evolved into more sustainable and reliable energy sources for now and tomorrow (IRENA, 2015b). This offers renewable energy as an economically feasible energy alternative.

CHAPTER THREE

3 METHODOLOGY

To be able to use energy technologies more sustainably there needs to be sustainability assessments to guarantee suitability before respective decisions to invest are taken into consideration. However, there are a number of methodologic issues of anticipation of future developments during development of assessment criteria which largely affect the accuracy of the criteria (Grunwald & Rösch, 2011).

MCDM is used to evaluate and analyze energy systems and resources for power generation so as to propose or select the best alternative for sustainable development and takes into account technical, financial, environmental, political, and social considerations. The main steps are:

- Problem definition
- Problem goal setting
- Method selection
- Alternative generation
- Criteria establishment
- Criteria weights assignment
- Construction of evaluation matrix
- Ranking of alternatives

3.1 Problem definition

For this work, a model for evaluating and prioritizing renewable energy resources and technologies for power generation and sustainable development of Uganda. The resource assessment conducted in Uganda shows that, Uganda has a huge renewable potential with about 80 percent electricity generation from renewables mainly hydro power. The energy resources mainly contributing to the energy mix of Uganda are: oil, biomass, hydropower and renewables. However, majority of their energy consumption is from fossil based fuel and propose alternatives are increasing the use of hydro, solar, geothermal, wind and geothermal since Uganda has a huge potential.

3.2 Method Selection

A variety of MCDM methods are currently in use to analyze, prioritized and evaluate energy systems and problems. Some of these methods are: VIKOR, AHP, TOPSIS, ELECTRE and PROMETHEE. They are used for energy problems such as renewable and energy planning, renewable energy resource ranking, prioritization of sustainable power generation technologies, renewable energy technology diffusion, ranking of energy projects etc. In this study, Analytical Hierarchy Process (AHP) method to evaluate the renewable energy technologies for sustainable development in Uganda. The AHP method facilitates technology alternative ranking by the provision of a framework that is able to deal with multiple objectives and provides the best compromised solution with contradictory objectives. Here, the problem is decomposed into hierarchies with the main goal at the top, criteria and sub criteria at the middle and the alternatives at the bottom.

The AHP method consist of the following steps:

- The decision problem is broken down into a hierarchical model of goals, criteria, sub criteria and alternatives.
- The goal is at the top of the hierarchy, criteria and sub criteria at the middle and the alternatives at the bottom.
- The weights of each level of the hierarchy is computed with respect to its immediate upper level. Objectives or parameters (A) and (B) are compared with respect to their parent node with pairwise comparison using nine-integer value.
- The eigen vectors are calculated to obtain priority weights and consistency checks.
- The consistency ratio (CR) is given by CI/RI where: RI = random consistency index and varies according to the number of variables in comparison (n); CI = consistency index and equals (λmax-n)/(n-1); λmax being the maximum eigenvalues of the comparison matrix.
- The scores of each criterion, sub criteria and alternatives are calculated.

3.3 Criteria and sub criteria

Renewable energy systems have a variety of decision making criteria or attributes and a single criterion such as cost benefit analysis or net present value is incapable of evaluating the system. Multiple attributes from different viewpoints: technical, economic, environmental, social, and political are usually considered. Technical and economic aspects are usually very crucial in energy planning and decision making, however the influence of environmental and socio-political aspects should not be ignored as they influence decision making as well.

The decision making criteria in renewable energy planning, systems or projects are usually selected from the vast number of criteria the exist in way that suits the needs and characteristics of the country concern. The main criteria used in renewable energy evaluation are: economic, technical, environmental and socio-political. The sub criteria are obtained from these main criteria. The sub criteria mainly used in literature for evaluating renewable and non-renewable energy sources are:

a. Economic sub criteria

Capital cost, operations and maintenance cost, research and development cost, cost of energy, operational life time, grid connection cost, fuel cost, market maturity, site advantage, funding availability and national economic development.

b. Technical sub criteria

Technology maturity, efficiency, reliability, resource availability or reserves, expert availability, time of deployment, energy system safety, availability of power supply, network stability, decentralization ease and safety in covering or meeting peak demand.

c. Environmental sub criteria

Emission reduction, land requirement, environmental impacts, disturbance of ecological balance and waste disposal needs or requirements.

d. Socio-political sub criteria

Social and political acceptance, job creation, health impacts, feasibility, compatibility with national energy policy, energy independency, Maintain leading position as energy supplier.

To construct the AHP model, we need to first omit the sub criteria that are non-influential in comparing renewable energy sources (fuel cost, waste disposal requirements etc.) and then use the sub criteria that are widely used in literature. Applying this, we obtain

e. Economic criteria

Capital cost, operations and maintenance cost, cost of energy, operational life time, national economic development.

f. Technical criteria

Technology maturity, efficiency, reliability, resource availability or reserves, energy system safety, network stability.

g. Environmental criteria

Emission reduction, land requirement, environmental impacts, ecological imbalance

h. Socio-political criteria

Social and political acceptance, job creation, compatibility with national energy policy, energy security, maintaining lead in energy production and supply.

Alternatives: Hydropower, Solar power, wind, geothermal, biomass energy.

The Analytical Hierarchy Process diagram for the prioritization of renewable energy technologies for the sustainable development of Uganda is shown

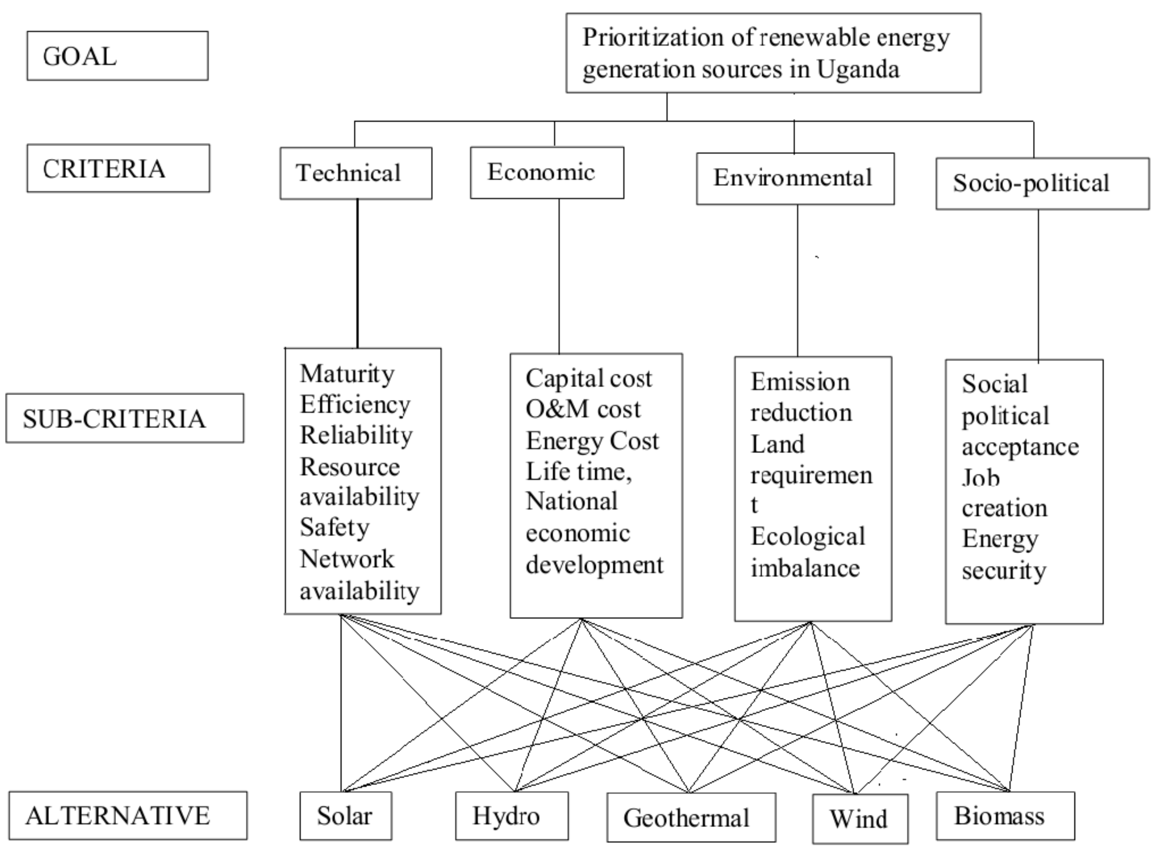

Figure 3-1: The Analytical Hierarchy Process diagram for prioritization of Renewable Energy Generation Sources for Uganda

3.4 Application of analytical hierarchy process model

The Sub-criteria are classified as qualitative and quantitative. Qualitative data are obtained subjectively (case of non-measurable) data by means of expert weighting. Quantitative data are obtained objectively through international databases, literature, or from developed countries database with similar projects. The pairwise comparisons of various criteria are organized into a square matrix with a diagonal of 1. The criterion in the ith row is better than that of the jth column if the value of element (i, j) is more than 1. If not, the criterion in the jth column is better than that in the ith row. Also, the (j, i) element of the matrix is the reciprocal of the (i, j) element.
The pairwise comparison of alternatives is done with respect to the gradation scale for quantitative comparison of alternatives.

Table 3-1: Gradation Scale for Pairwise Comparison of Alternatives (5,7)

Option (How important is A relative to B?)	Numerical value(s)
Equal	1
Marginally strong	3
Strong	5
Very Strong	7
Extremely strong	9
Intermediate values to reflect fuzzy inputs	2, 4, 6, 8
Reflecting dominance of second alternative compared to first	Reciprocals

The consistency (Consistency Index, CI) of the matrix of n order is evaluated. CI is compared with the random matrix, RI. The consistency ratio (CR) is given by CI/RI. The best value of CR should be less than 0.1. If not, the answer needs to be re-examined. The Randomness Index for various values of n are as shown:

Table 3-2: Randomness Index for Various Values

n	2	3	4	5	6	7	8	9
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The rating of each alternative is then multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings.

The principal eigenvalue and corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives (8). To calculate the weight of the criteria:

1. The geometric mean of each row in the matrix is calculated (multiply each criterion score in the row and take the nth root of the product; n = number of criteria).
2. The geometric means are summed, and
3. The geometric means are normalized by dividing by the sum computed to get the weight of the criteria.
4. The criteria are ranked.

The results of this study provide a rank of the different energy generation sources based on evaluation of the key considerations of renewable energy source deployment i.e. technical, economic, environmental and socio-political. This will inform policy on which renewable resources should be highly prioritized for energy generation for sustainable economic development of Uganda.

3.5 Data used

Technical data

Economic data

Environmental data

Socio-political data

3.6 Power plant economic analysis

The levelized cost of energy is the main economical factor used for comparing different energy generation technologies (Solar, wind, biomass nuclear etc.). It is defined as the cost of each unit of energy generated during the analysis period of the selected plant. This factor is calculated using the summation of primary investment and operation and maintenance costs divided by the energy generated from the power plant during its life span. The method used in LCOE calculation is based on net present value approach, where the expenses for investment and the payment flow from earnings and expenses during the system life span are determined based on discounting from a reference date.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Where:

LCOE: Levelized cost of electricity in $/kWh

I_0: Investment expenditures in $

A_t: Annual total costs in $ in year t

$M_{t,\,el}$: Produced quantity of electricity in the respective year in kWh

i: Real interest rate in %

n: Economic operational lifetime in years

t: Year of lifetime (1, 2, ...n)

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Weight of Main Decision Criteria with Respect to the Goal

Figure 4-1 shows the weight of the main decision criteria with respect to the goal. The secondary axis provides the weighting criteria based on economic, technical, environmental and social political aspects of renewable energy technology deployment whereas the primary axis indicates the weight of the criteria. This graph enables us to determine the relative importance of particular decision criteria in respect to goal achievement.

Figure 4-1: Weight of the main decision criteria with respect to the goal

From the results obtained environmental and technical criteria are the most important criteria with respect to the goal with a score of 39.44% and 31.91% respectively followed by social political 22.56% and the least being economic criteria scoring 6.09%. The figure below shows the weight of the main decision criteria with respect to the goal of prioritization for renewable energy generation sources for Uganda.

Table 4-1 shows consistency ratio of the main decision criteria with respect to the goal. The consistency ratio is an indicator of the randomness of variable. A consistency ratio of less than 0.1 is preferred for this form of comparison and indicates low randomness of the variables.

Table 4-1: Consistency Ratio of Main Decision Criteria with respect to the goal

Matrix product of row and weight column	Ratio matrix product to weight
0.24559705	4.035686149
1.332727264	4.176428706
1.684244894	4.270461715
0.962159205	4.264083758
CI	0.062221694
RI	0.9
CR	0.069135216

Calculation for Consistency Index for the weight of the main decision making criteria with respect to the main goal is computed below. The consistency ratio is 0.069 which is less than the minimum of 0.1. This implies that there is no need to cater for randomness of the values.

4.2 Weight of sub criteria in respect to the parent criteria

Figure 4-2 shows the weight of the sub criteria with respect to the parent criteria. It represents the breakdown of parent criteria i.e. economic, technical, environmental, and socio political criteria into more specific sub criteria such as capital cost, operation and maintenance costs, energy cost, lifetime, technological maturity, efficiency, reliability, resource availability, safety, emission reduction, land requirement, ecological imbalance, job creation, socio political acceptance and energy security to define their relative importance to the parent criteria. This enables decision makers to make high consideration of these aspects when considering deployment of various energy resources in the country.

The various sub criteria are ranked based on either expert opinion of available data that is specific to them such as levelized cost of electricity, carbon emission reduction, initial capital investment, job creation among others.

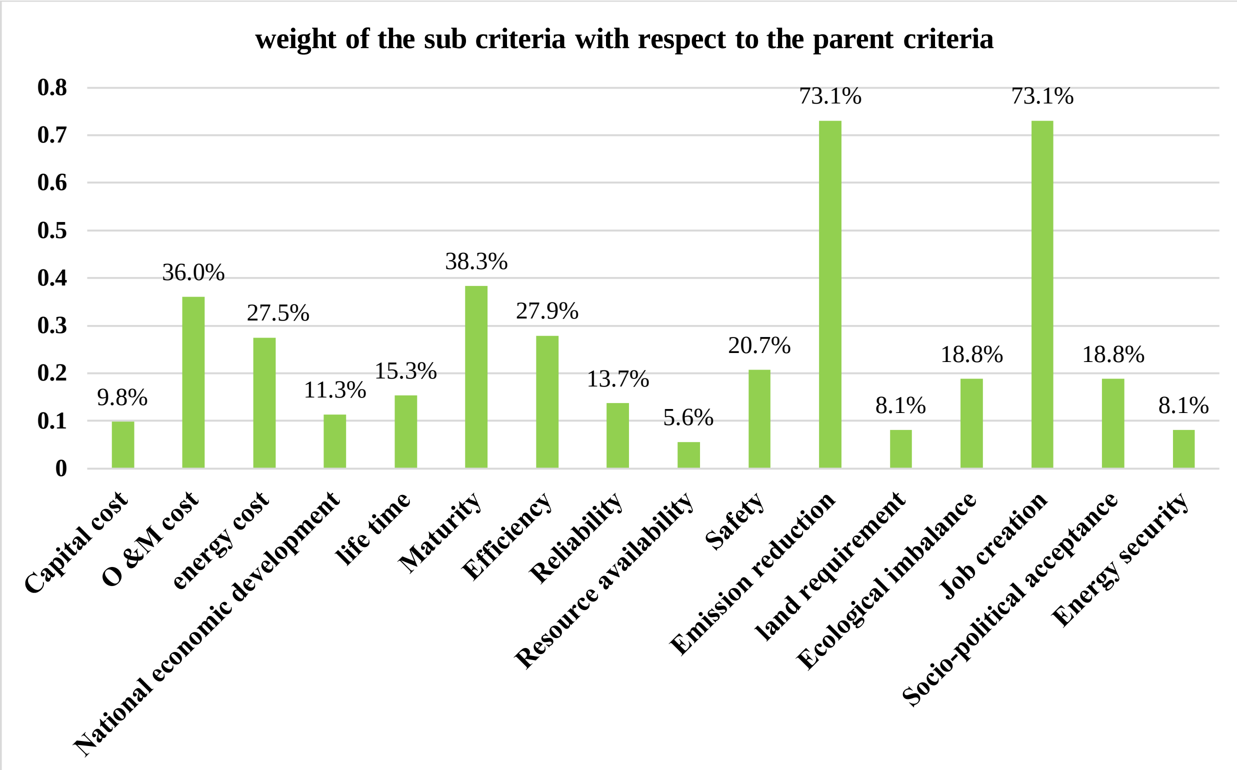

Figure 4-2: Weight of the Sub criteria with respect to the parent criteria

Weight of sub-criteria in comparison with the parent criteria reveals that the most important aspect in the economic criteria is operation and maintenance cost at 36% followed by energy cost at 27.5% and 11.3%, 9.8% for national economic development and capital cost respectively.

Evaluation of technical sub criteria with respect to the parent criteria reveals technological maturity as the most important aspect at 38.3% followed by efficiency at 27.9% and 20.7%, 15.3%, 13.7%, 5.6% for safety, life time, reliability and resource availability respectively.

The weight of the environmental sub criteria with respect to the parent criteria reveals emission reduction as the most important aspect at 73.1 % followed by ecological imbalance 18.8% and land requirement at 8.1 %.

The socio political sub criteria evaluation in respect to the parent criteria shows that job creation is the most important aspect at 73.1% followed socio political acceptance at 18.8% and energy security at 8.1%.

4.3 Weight of the alternatives with respect to each decision criterion

Figure 4-3 shows the weight of each of the alternatives with respect to each criterion i.e. economic, technical, environmental and socio-political. The different generation technologies are compared in a pairwise manner with respect to the decision criterion and various weights obtained which indicate the relative importance of various criteria considerations in the deployment of the different generation sources of energy.

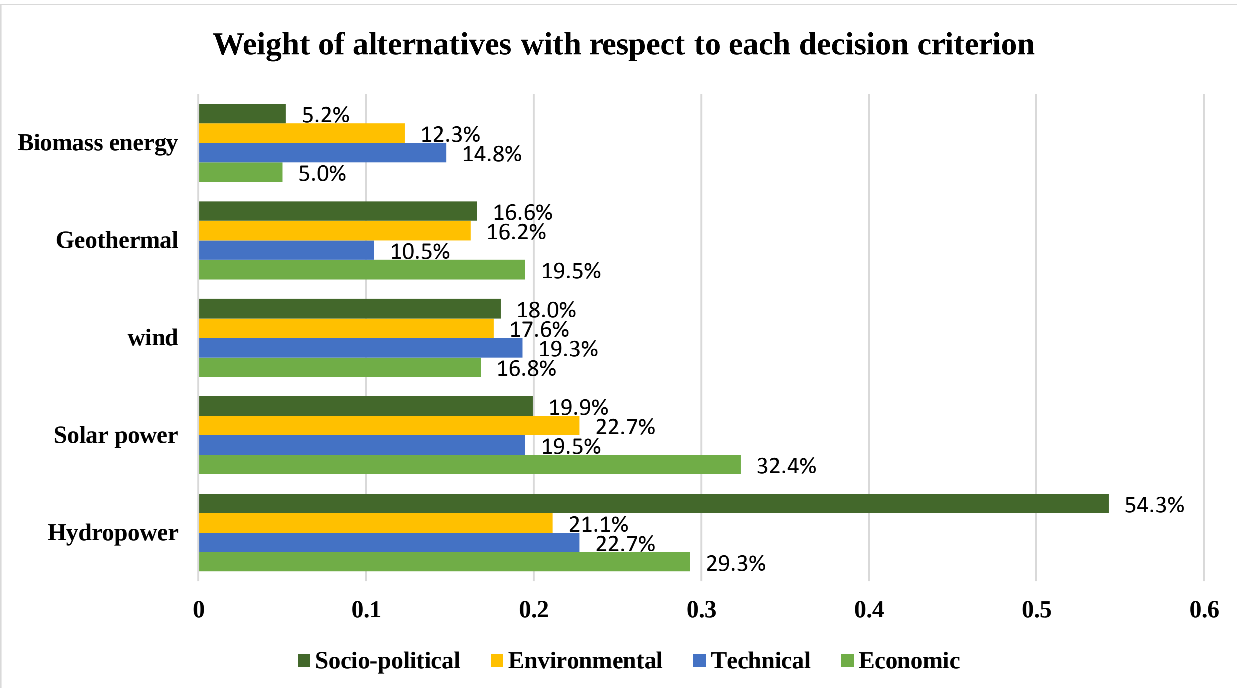

Figure 4-3: Weight of the alternatives with respect to each decision criterion

The economic criterion indicates solar energy as the leading option with 32.4%, followed by hydropower at 29.3% and 19.8%, 16.8%, 5.0% for geothermal, wind and biomass respectively.
The technical criterion avails hydropower as the leading option at 22.7% followed by solar at 19.5% and 19.3%, 14.8%, 10.5% for wind, biomass energy and geothermal respectively.
The environmental criterion indicates solar as the leading generation source at 22.7% followed by hydropower at 21.1% and 17.6%, 16.2%, 12.3% for wind, geothermal and biomass respectively.
The socio-political criterion shows hydro-power as leading with 54.3% followed by solar at 19.9% and 18.0%, 16.6%, 5.2% for wind, geothermal and biomass respectively.

4.4 Priority weight(ranking) of renewable energy generation source alternatives

Figure 4-4 shows the priority ranking of the various renewable energy generation sources on the overall. This ranks the generation sources in order of priority depending on the parent criteria and sub criteria to enable the government set priorities on which generation source is best suited for investment in a particular country.

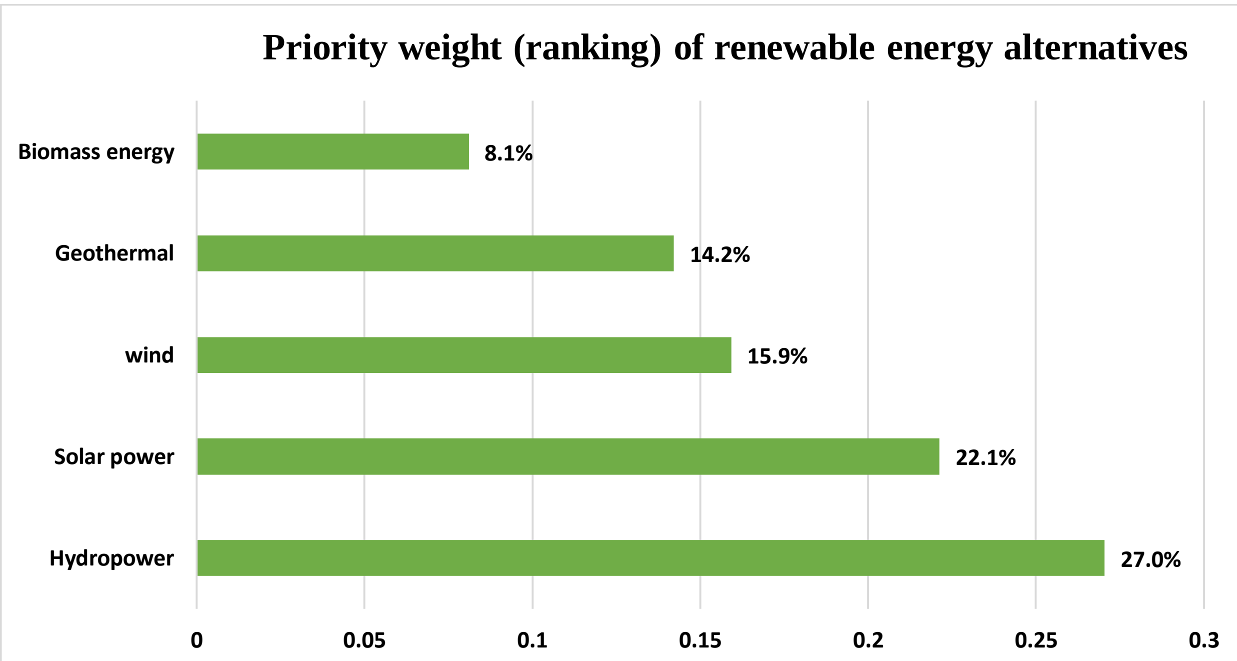

Figure 4-4: Priority weight (ranking of renewable energy generation source alternatives

The priority ranking of the renewable energy generation sources indicates that hydro power is the first alternative generation source at 27.0% followed by solar power at 22.1% and 15.9% 14.2 %, 8.1% for wind, geothermal and biomass energy respectively. This implies that the government of Uganda and other stakeholders in the renewable energy marked need to highly consider these aspects in energy investment.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There are strong inter linkages between human life, environmental protection, economic development and social issues. Energy is essential to transformation of human productivity and improvement of living standards though may at the same time have devastating effects at local regional and global scale(Cary, 2017). Therefore, deployment of renewable energy generation sources has to take into considerations aspects of environment, economy, technical and social issues in order to guarantee sustainability of the renewable energy sources.

The energy resource assessment of Uganda indicates that Uganda has various renewable generation potentials that are crucial to sustainable economic development. The research indicates that Uganda hydro power potential of about 2,200 MW, Solar Energy potential of about 200MW, Bioenergy potential of 1650MW, Geothermal Energy of 450MW, and wind speeds ranging between 3-5 M/s. This generation potential is sufficient to meet Uganda's current energy needs.

The study creates rational criteria and sub criteria for decision making on which basis evaluation and comparison of various generation sources is assed to determine the most suitable energy generation source for Uganda.

From the results obtained environmental and technical criteria are the most important criteria with respect to the goal with a score of 39.44% and 31.91% respectively followed by social political 22.56% and the least being economic criteria scoring 6.09%. This implies that prioritization of renewable energy deployment is majorly hinged on these two fundamental aspects.

Weight of sub-criteria in comparison with the parent criteria reveals that the most important aspects operation and maintenance cost at 36% for economic criteria technological maturity at 38.3% for technical criteria, emission reduction at 73.1% for environmental criteria and job creation at 73.1% for socio political criteria. This implies that in renewable energy deployment, high consideration of these sub criteria should be taken compared to other sub criteria.

The comparison of renewable energy generation source alternatives indicate that solar energy is the leading option with respect to economic criterion at 32.4%, hydropower as the leading option at 22.7% with respect to technical criteria, solar as the leading generation source at 22.7% with respect to environmental criterion and hydro-power as leading with 54.3% with respect to socio political criterion. This implies that solar energy presents lower economic costs than hydro power on the overall and as well presents higher environmental benefits on the overall. On the other hand, the results imply that hydro power is more suitable technologically in terms of aspects such as maturity among others, it also indicates that hydro power presents more socio political benefits compared to solar energy.

Based on the criteria presented by this research the priority ranking of the renewable energy generation sources indicates that hydro power is the first alternative generation source at 27.0% followed by solar power at 22.1% and 15.9% 14.2 %, 8.1% for wind, geothermal and biomass energy respectively. This ranking implies that the deployment of renewable energy in terms of generation sources should be considered based on the order of the rankings to achieve benefits accruing to generation sources and develop sustainably.

5.2 Recommendations

Specific sub criteria such as carbon emission reduction need to be calculated based on a life cycle assessment for all renewable technologies in order to understand the actual carbon emission reduction effect of each technology once deployed to tap into these resources

Determining the most suitable renewable energy generation sources may include several aspects such as Economic sub criteria research and development cost, grid connection cost, fuel cost, market maturity, site advantage, funding availability, Technical sub criteria such as expert availability, time of deployment, availability of power supply, network stability, decentralization ease and safety in covering or meeting peak demand, Environmental sub criteria such as waste disposal needs or requirements, Socio-political sub criteria such as health impacts, feasibility, compatibility with national energy policy, energy independency, ease of maintaining leading position as energy supplier among others which this research did not cater for either because of lack of data or complexities in assigning rankings and making reasonable comparisons based on the time frame allocated. It is recommendable that further research be carried out to detail these aspects of sustainability of renewable energy generation sources.

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APPENDIX

Table 5-1: Pairwise matrix for the comparison of the criteria with the goal

Pairwise matrix for the comparison of the criteria with the goal										
Criteria	**Economic**	**Technical**	**Environmental**	**Socio-political**		**Geometric mean (row)**	**Weight**	**Rank**	**Matrix product of row and weight column**	**Ratio matrix product to weight**
Economic	**1.000**	**0.167**	**0.143**	**0.333**		**0.298**	**0.061**	**4.000**	**0.246**	**4.036**
Technical	**6.000**	**1.000**	**0.500**	**2.000**		**1.565**	**0.319**	**2.000**	**1.333**	**4.176**
Environmental	**7.000**	**2.000**	**1.000**	**1.000**		**1.934**	**0.394**	**1.000**	**1.684**	**4.270**
Socio-political	**3.000**	**0.500**	**1.000**	**1.000**		**1.107**	**0.226**	**3.000**	**0.962**	**4.264**
					sum	**4.905**			**CI**	**0.062**
									RI	**0.9**
									CR	**0.0691**

Table 5-2: Pairwise matrix for the comparison of the economic sub criteria to the economic criteria

Pairwise matrix for the comparison of the economic sub criteria to the economic criteria											
Sub Criteria	Capital cost	O &M cost	energy cost	National economic development	life time		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Capital cost	1.000	0.500	0.143	3.000	0.250		0.557	0.098	5.000	0.658	6.711
O &M cost	2.000	1.000	3.000	3.000	2.000		2.048	0.360	1.000	1.722	4.778
energy cost	7.000	0.333	1.000	2.000	2.000		1.563	0.275	2.000	1.308	4.755
National economic development	0.333	0.333	0.500	1.000	2.000		0.644	0.113	4.000	0.404	3.560
life time	4.000	0.500	0.500	0.500	1.000		0.871	0.153	3.000	0.920	6.003
						sum	5.683			CI	0.040
										RI	1.120
										CR	0.036

Table 5-3: Pairwise matrix for the comparison of the technical sub criteria to the technical criteria

Pairwise matrix for the comparison of the technical sub criteria to the technical criteria											
	Maturity	Efficiency	Reliability	Resource availability	Safety		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Maturity	1.000	3.000	7.000	7.000	0.333		2.178	0.383	1.000	2.569	6.702
Efficiency	0.333	1.000	3.000	5.000	2.000		1.585	0.279	2.000	1.096	3.930
Reliability	0.143	0.333	1.000	3.000	2.000		0.778	0.137	4.000	0.452	3.298
Resource availability	0.143	0.200	0.333	1.000	0.333		0.316	0.056	5.000	0.212	3.805
Safety	3.000	0.500	0.500	3.000	1.000		1.176	0.207	3.000	1.732	8.368
						sum	6.034			CI	0.055
										RI	1.120
										CR	0.049

Table 5-4: Pairwise matrix for the comparison of environmental sub criteria to environmental criteria

Pairwise matrix for the comparison of the environmental sub criteria to the environmental criteria									
	Emission reduction	land requirement	Ecological imbalance		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Emission reduction	1.000	7.000	5.000		3.271	0.731	1.000	2.239	3.065
land requirement	0.143	1.000	0.333		0.362	0.081	3.000	0.248	3.065
Ecological imbalance	0.200	3.000	1.000		0.843	0.188	2.000	0.577	3.065
				sum	4.477			CI	0.032
								RI	0.580
								CR	0.056

Table 5-5: Pairwise matrix for the comparison of the socio-political sub criteria to the socio-political criteria

Pairwise matrix for the comparison of the socio-political sub criteria to the socio-political criteria									
	Job creation	Socio-political acceptance	Energy security		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Job creation	1.000	5.000	7.000		3.271	0.731	1.000	2.239	3.065
Socio-political acceptance	0.200	1.000	3.000		0.843	0.188	2.000	0.577	3.065
Energy security	0.143	0.333	1.000		0.362	0.081	3.000	0.248	3.065
				sum	4.477			CI	0.032
								RI	0.580
								CR	0.056

Table 5-6: Pairwise matrix for the comparison of alternatives with respect to the economic criteria

Pairwise matrix for the comparison of alternatives with respect to the economic criteria											
	Hydropower	Solar power	wind	Geothermal	Biomass energy		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Hydropower	1.000	0.143	5.000	3.000	6.000		1.667	0.293	2.000	1.766	6.020
Solar power	7.000	1.000	3.000	0.200	5.000		1.838	0.324	1.000	2.920	9.027
wind	0.200	0.333	1.000	3.000	4.000		0.956	0.168	4.000	0.919	5.464
Geothermal	0.333	5.000	0.333	1.000	3.000		1.108	0.195	3.000	1.966	10.089
Biomass energy	0.111	0.200	0.250	0.333	1.000		0.284	0.050	5.000	0.254	5.087
						sum	5.853			CI	0.534
										RI	1.120
										CR	0.477

Table 5-7: Pairwise matrix for the comparison of alternatives with respect to the technical criteria

Pairwise matrix for the comparison of alternatives with respect to the technical criteria											
	Hydropower	Solar power	wind	Geothermal	Biomass energy		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Hydropower	1.000	0.200	3.000	2.000	3.000		1.292	0.227	1.000	1.056	4.644
Solar power	5.000	1.000	0.500	0.333	2.000		1.108	0.195	2.000	1.463	7.508
wind	0.200	2.000	1.000	2.000	2.000		1.099	0.193	3.000	0.838	4.336
Geothermal	0.250	3.000	0.500	1.000	0.200		0.596	0.105	5.000	0.843	8.042
Biomass energy	0.333	0.500	0.500	5.000	1.000		0.839	0.148	4.000	0.942	6.376
						sum	4.933			CI	0.295
										RI	1.120
										CR	0.264

Table 5-8: Pairwise matrix for the comparison of the alternatives with respect to the environmental criteria

Pairwise matrix for the comparison of alternatives with respect to the environmental criteria											
	Hydropower	Solar power	wind	Geothermal	Biomass energy		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Hydropower	1.000	5.000	0.333	0.500	3.000		1.201	0.211	2.000	1.488	7.040
Solar power	0.200	1.000	3.000	2.000	3.000		1.292	0.227	1.000	1.122	4.935
wind	3.000	0.333	1.000	0.500	2.000		1.000	0.176	3.000	0.967	5.495
Geothermal	2.000	0.500	2.000	1.000	0.333		0.922	0.162	4.000	1.051	6.475
Biomass energy	0.333	0.333	0.500	3.000	1.000		0.699	0.123	5.000	0.844	6.863
						sum	5.114			CI	0.290
										RI	1.120
										CR	0.259

Table 5-9: Pairwise matrix for the comparison of the alternatives with respect to the socio-political criteria

Pairwise matrix for the comparison of alternatives with respect to the Socio-political criteria											
	Hydropower	Solar power	wind	Geothermal	Biomass energy		Geometric mean (row)	Weight	Rank	Matrix product of row and weight column	Ratio matrix product to weight
Hydropower	1.000	5.000	4.000	2.000	7.000		3.086	0.543	1.000	2.593	4.774
Solar power	0.200	1.000	0.333	4.000	7.000		1.133	0.199	2.000	1.033	5.179
wind	0.250	3.000	1.000	0.500	3.000		1.024	0.180	3.000	0.997	5.534
Geothermal	0.500	0.250	2.000	1.000	3.000		0.944	0.166	4.000	0.848	5.103
Biomass energy	0.143	0.143	0.333	0.333	1.000		0.296	0.052	5.000	0.274	5.254
						sum	6.483			CI	0.042
										RI	1.120
										CR	0.038

Table 5-10: Summary of the comparison of alternatives with respect to the criteria and overall prioritization of alternatives

Summary of the Comparison of alternatives with respect to the criteria and overall prioritization of alternatives							
	Economic	**Technical**	**Environmental**	**Socio-political**	**Criteria weight**	**Product Matrix row and criteria weight column**	**Alternative ranking**
Hydropower	0.293	0.227	0.211	0.543	0.319	0.270	1
Solar power	0.324	0.195	0.227	0.199	0.236	0.221	2
wind	0.168	0.193	0.176	0.180	0.179	0.159	3
Geothermal	0.195	0.105	0.162	0.166	0.157	0.142	4
Biomass energy	0.050	0.148	0.123	0.052	0.093	0.081	5

Table 5-11: Overall sub criteria weights

Sub Criteria	Weight
Capital cost	0.098001
O &M cost	0.360334
energy cost	0.275076
National economic development	0.113396
life time	0.153193
Maturity	0.383252
Efficiency	0.278898
Reliability	0.136972
Resource availability	0.055691
Safety	0.206958
Emission reduction	0.730645
land requirement	0.080961
Ecological imbalance	0.188394
Job creation	0.730645
Socio-political acceptance	0.188394
Energy security	0.080961