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HYDRO, SOLAR, AND WIND: ENERGY POLICY IMPLICATION IN RENEWABLE ENERGY DEPLOYMENT IN RWANDA

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DECLARATION

I **Michel Rwema**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material, and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

ABSTRACT

Rwanda energy sector is one of the important drivers for her economic transformation and livelihood improvement of her population toward the country's vision 2020. The sector currently needs a high attention to sustain country's growth economy by ensuring the effective deployment of all potential energy sources available within the country to increase energy production. However, the potential energy resources deployed in Rwanda are promoted by current Rwanda energy policy with different effort. Hydro, Solar, and Wind are among the renewable energy resources in Rwanda, and their contribution are differents in Rwanda energy generation. This thesis was conducted with aim of studying the potential of renewables (Solar and wind) in five locations (Nyagatare, Byumba, Kanombe, Butare, and Ruhengeri) and to find the gaps in Rwanda energy sector delaying deployment of renewables such as Hydro, Solar, and the Wind in energy generation. Current energy policy, energy sector strategic plan and other Rwanda energy related reports and articles were reviewed. Solar radiation and wind speed data recorded in 2015 from five locations were analyzed using Excel. The potential for solar was found in these five locations and one location for wind potential identified (Kanombe) with 5.3 m/s at 150m heights. Deployment of Hydro among other renewable energy resources in Rwanda energy generation was high and far more promoted by the current energy policy. We concluded by confirming that Hydro is highly promoted (with 60% of total installed capacity) regardless its limited potential and the potential of other renewables in Rwanda. There is a high need for diversification in energy generation. Solar has good potential and Wind potential in some locations are good to some extent. Renewable energy sources (Solar and Wind) can contribute significantly positive to Rwanda energy sector if all the identified gaps addressed very well.

Keywords: Renewable energy, Energy Policy, resource potential, Rwanda

RÉSUMÉ

Le secteur de l'énergie au Rwanda est l'un des moteurs importants de sa transformation économique et de son amélioration de la subsistance vers la vision 2020 du pays. Le secteur a actuellement besoin d'une attention particulière pour soutenir la croissance économique du pays en assurant le déploiement efficace de toutes les sources potentielles d'énergie renouvelables disponibles en production énergique effective. Cependant, la politique énergétique du Rwanda encourage le déploiement d'Hydro, du solaire et d'éolienne avec différents efforts dans la production d'énergie du Rwanda. Cette thèse a été menée dans le but d'étudier le potentiel des énergies renouvelables (solaire et éolienne) dans cinq localités (Nyagatare, Byumba, Kanombe, Butare et Ruhengeri) et de trouver les problèmes du secteur de l'énergie du Rwanda pour déployer des énergies renouvelables telles qu'Hydro, Solaire, Et l'éolienne dans la génération d'énergie. La politique énergétique actuelle, le plan stratégique du secteur de l'énergie et d'autres rapports et articles relatifs à l'énergie au Rwanda ont fait l'objet d'une étude. Les données de rayonnement solaire et des vitesses du vent de ces cinq localités enregistrées en 2015 ont été analysées à l'aide d'Excel. Le potentiel d'énergie solaire a été trouvé dans ces cinq endroits et une localité avec un potentiel éolien (Kanombe), ayant 5,3 m / s à 150 m de hauteur. Le déploiement d'Hydro entre d'autres ressources énergétiques renouvelables au Rwanda est élevé et beaucoup plus favorisé par la politique énergétique actuelle. Nous avons conclu en confirmant que l'Hydro est fortement promu (avec 60% de la capacité installée totale) sans considérer son potentiel limité et le potentiel d'autres énergies renouvelables au Rwanda. Il y'a un besoin élevé de diversification de la production d'énergie. L'énergie solaire a un bon potentiel et le potentiel éolien dans certaines localités est bon dans une certaine mesure. Les sources d'énergie renouvelable (solaire et éolienne) peuvent contribuer de manière significative au secteur énergétique du Rwanda si toutes les lacunes identifiées sont très bien abordées.

Mots clés : Énergie renouvelable, Politique énergétique, potentiel de ressources, Rwanda

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LIST OF ABBREVIATIONS AND ACRONYMS

AESG	Africa Energy Services Group LTD
AfDB	African Development Bank
AU	African Union
EARP	Electricity Access Rollout Programme
EDCL	Energy Development Corporation Limited
EDPRS	Economic Development and Poverty Reduction Strategy
EICV	Enquête Intégrale sur les Conditions de Vie des Ménages (Integrated Household Living Conditions Survey)
EUCL	Energy Utility Corporation Limited
GDP	Gross Domestic Product
GIS	Geographic Information System
h	Tower height(m)
HFO	Heavy Fuel Oil
ICT	Information and Communication Technology
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
JICA	Japanese International Cooperation Agency
kWh	Kilowatt-hour (Unity of energy)
LPG	Liquefied Petroleum Gas

MININFRA Rwanda Ministry of Infrastructure

MW Mega Watt

n Power law exponent

NISR National Institute of Statistics of Rwanda

P Wind Power density(W/m^2)

PAUWES Pan African University Institute of Water and Energy Sciences

PV Photovoltaic

REG Rwanda Energy Group

REMA Rwanda Environment Management Authority

RURA Rwanda Utilities Regulatory Authority

Rwfs Rwandan Francs

SHS Solar Home System

SNV Netherlands Development Organisation

SWHS Solar Water Heater System

TV Television

v Wind speed(m/s)

VAT Value Added Tax

WASAC – Water and Sanitation Corporation

Wh Watt hour

ρ Air Density(Kg/m^3)

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Chapter 1. INTRODUCTION

1.1 Background Information

As the world wants to reduce the use of fossils to mitigate greenhouse gasses emission, many countries are asking what to do in that regard to save the world from temperature rising and climate change. The solution highlighted for this issue is to use renewable energy resources. While reducing gasses emeission, Africa with abundant renewables, they can be used to provide solutions for power shortage, inaccessibility of electricity and sustain economic development growth within the continent (IRENA, 2015a). However, it is not easy to deploy renewable energy sources because they require different technologies of which some are very expensive and are not available in all the regions. This makes the difference in the development of renewables between developing and developed countries. The source like Solar and Wind dominates renewable energy sources to be deployed in energy generation globally. However, the large share is from few number of the developed country. While these two are developing, the other sources are witnessing a decrease in the renewable energy market. The commitment and successful use of renewables in different regions are highly explained by the resources available and energy policies in place. The energy policies developed within the countries shows where much efforts are put and how the energy resources are favored in deployment. It is in this view, we can observe the difference in renewables deployment from region to region, and country to country. The African continent has abundant energy resources and less technology to harvest them. This is among the common major barriers to renewable energy deployment within the continent. The countries are building their economic while adopting the use of renewables. The sustainable economic development relying on the deployment of renewables to mitigate climate change could be found in all African countries. The African continent is committed to this initiative, but the real commitment of the mainland is what each of country as the member does for this to happen.

The interstate cooperation and region integration have grown toward the development of energy sector in Africa. Rwanda in East Africa, as among the first growing economy in Africa, still facing the challenge of insufficient energy to meet high demand due to population growth and economic development. The energy production within the country is highly depending on Hydropower regardless the potential of other renewable energy resources (JICA, 2016) and its susceptibility to climate change effect due to the fact that it is sensitive to the amount, timing, and geographical patterns of precipitations and temperature (Ministry of Infrastructure, 2015a). This recall the implication of current energy policy in resource deployment in the country. Identically to many countries, renewable energy resources are not promoted with the same effort and the energy policies are pointed to be the main reasons behind this. Rwanda is taking action every day to bring meaningful change in the energy sector for sustaining the force of this anti-climate change initiative as well as strengthening her economic growth.

With aim of having a deep understanding of Rwanda's renewable energy resources highly focusing on Hydro, Solar, and the wind, in this work, we will investigate the impact of Rwanda energy policy in renewable energy deployment. This thesis is organized as follows: In Chapter two, we introduced energy sources and current country energy overview with much focus on the contribution of renewable energy resources in energy generation. Then, after having an image of the country energy sector, we discussed in Chapter three the growing process and the potential of Hydro, Solar, and Wind in power generation. We discussed the implication of energy policy in the development of these three energy resources and also challenges and barriers affecting the development of renewables in the country. Finally, in Chapter four, based on our findings, we conclude and policy recommendations were given.

1.2 Problem Statement

Currently, energy and related issues in all sectors are among the top main challenges in Africa development. Rwanda like most of the sub-Sahara African country emphasizes energy equity including accessibility and affordability (IEA, 2014). The demand for energy

is growing dramatically due to both economic activities growth and the increasing country population. This is the major challenge in Rwanda energy sector where the installed electricity capacity is very low at this time (208 MW). In addition to this, there is a high dependence on Hydro power generation regardless its limit potential. It contributes about 60% of total installed capacity (Ministry of Infrastructure, 2015c) (JICA, 2016). The policy in place is highly favoring hydro among other energy resources. Most of the plan and projects are focusing on its use in increasing the electricity production regardless the risks we mentioned above and the potential of other sources such as solar and the wind in different stations.

Energy is very important means to sustain the economy due to its ability to increase economic activities and livelihood improvement. That is why much attention and development of different alternatives in power generation is needed to sustain country's development and overcoming the challenge of high energy demand. If the current plan to boost energy generation highly considers renewable energy sources (Solar and Wind), it can help considerably to mitigate the energy challenge in Rwanda.

1.3 Objectives of the Study

The main objective

The main objective of this study is to show the impact of energy policy on the deployment of renewables in the sustainable economic growth of Rwanda, highly focusing on the contribution of Hydro, Solar, and Wind in energy production.

The specific objective

The study intended to:

- Evaluate country's renewable energy resources and their potential
- Evaluate and analyze renewable energy source's contribution in electricity generation mainly focusing on Hydro, Solar, and Wind
- Evaluates economic and market potential of renewables within the country

- Investigate the impact of Rwanda energy policy to the deployment and development of Hydro, Solar, and Wind while identifying the gap within in energy sector.

1.4 Research Questions

Main Question

- Does Rwanda energy policy promote the use of renewables in energy production?
- Are Hydro, Solar, and Wind being promoted in Rwanda energy production equitably?

Secondary questions

- What is Rwanda installed capacity?
- What do renewables sources contribute in power generation?
- What do Hydro, Solar, and Wind contribute in power generation?
- What is suitable alternative energy resources for Rwanda?
- What are renewable energy technologies available in Rwanda?
- What is market potential for renewables?
- What is the role of energy policy in renewable energy deployment in Rwanda?

1.5 Scope and limitation

The study was undertaken in Rwanda from March up to July 2017. It involved the collection of meteorological data (such as wind speed and solar irradiation) from Rwanda meteorology agency for stations including Butare, Byumba, Kanombe, Nyagatare, and Ruhengeri. These five locations were chosen because they are representative stations of South, North, Kigali City and Eastern province, and some of them have a high percentage of people with no electricity. Other information we need include:

- Energy resources and their potential
- Energy production and consumption
- Demographic and economic data

After that, we analyzed these data using Excel tool.

1.6 Methodology

The data we need to collect for our research in details include:

- Meteorological data: - Solar irradiation
  - Wind speed
- Energy data: - Total energy production
  - Total renewable energy plants and their capacities
  - Hydro, Solar and wind shares in energy production
  - Energy consumption by sector
  - Total Energy import/ export
  - Current and planned energy projects
- Demographic and Economic Data:
  - in this, we need to know Rwandan population how they were growing based on population increment for some years.
  - economic data we need here was GDP as an indicator of country's economic, we used it to identify how it was increasing for some years.

As separated above, the meteorological data was collected from Rwanda Meteorology Agency, while all the energy data was from Ministry of Infrastructure and Rwanda Energy Group. The demographic and economic data from the National Institute of Statistics of Rwanda.

To get information from the numerical data we analyzed them, it required a tool. The data analyzed using Excel. Like other tools, Excel was able to provide the information we needed. The Excel helped to:

- Present and analyze meteorological data from location we selected
- Presents and analyze the state of energy sector,
- Presents the contribution and growth state of renewable energy resources in Rwanda energy production.

- Presents and analyze the share of Hydro, Solar, and Wind in energy production.

- Presents and relates population, economy, and energy.

Chapter 2. LITERATURE REVIEW

2.1 Hydro, Solar, and Wind Energy Sources

We always appreciate and value the presence of energy when we want to perform some work. Energy in form of electricity is playing a great role in all sectors across the world. Currently, technology is being improved to harness this energy from different energy sources such as Hydro, Solar, and wind energy sources.

Hydropower is generated by mechanical conversion of the energy into electricity through a turbine. Depending on the state of water flowing all the year, its quantity, height, and turbine specification, hydro power can be obtained for various use (John, et al., 1974). Hydro remains important in power supply in most African countries.

The Sun is an amazing source of energy which is inexhaustible in most of the part of the world. Most of the energy is in the form of light and heat, which can be collected and used for generating electricity, as well as for cooking, heating, cooling, and lighting (EAI, 2017). Photovoltaic (solar) cells and solar thermal systems are used to convert the Sunlight directly into electricity and heat respectively. The photovoltaic(solar) cells are made of semiconductors used to collect solar Sunlight and convert it directly into electricity (EAI, 2017). The photovoltaic can be fixed on the roofs or the ground near homes and buildings.

Wind energy has become one of today's best renewable energy technology for energy generation. Wind energy is harnessed by use of wind turbine. A wind energy system changes the kinetic energy contains in the wind into mechanical or electrical energy to be used for various applications (Safari & Gasore, 2010). According to American Wind Energy Association, the wind is classified based on its annual average wind speed. The annual average wind speeds of 5 meters per second are required for grid-connected applications while annual average wind speeds of 3 to 4 meters per second may be adequate for non-connected electrical and mechanical applications such as battery charging and water pumping (American Wind Energy Association, 2017).

2.2 Country Energy Overview

The energy use in Rwanda is mainly from three energy sources: Bioproducts, Petroleum, and Electricity. Bioproducts which is majorly dominated by wood and its derivative almost its quantity contribute in heating and cooking. Currently, Biomass represents 85% in Rwanda total energy use. A large number of households in rural areas relying on firewood. The government's plan is to reduce intensity use of fuel wood to 50% by 2018. The planned way to reduce this is through encouraging the use of alternative fuels (Peat, LPG, Biogas), increasing the efficiency of charcoaling technologies and improved cook stoves (ex, Canarumwe, Tekavuba stoves), and improving the production and distribution of wood fuels (SNV, 2015) (Ituze, et al., 2017).

Petroleum still playing a great role in transport and industrial sector. As the country is developing by promoting industries and the there are no other alternative fuels in transport, this implies the still dominance of petroleum for this two-sector. The use of petroleum and its derivative in both sectors contributes with a huge amount of Carbon emission within the country. In most case the reduction of carbon emission highly depend on efficiency measures and high deployment of renewables (Dolf Gielen, et al., 2015b) and this still needed for Rwanda.

Electricity generated and import is used in lighting, modern domestic and commercial technologies, and industrial processing. At the household level, electricity consumption dominantly stands at 51% and is primarily used for lighting systems. The second largest consumer of Rwanda's total electricity is the industrial sector utilizing 42%. The public sector uses about 6% for street lighting, powering public buildings and water pumping (Ministry of Infrastucture, 2015b) [Figure 2.1].

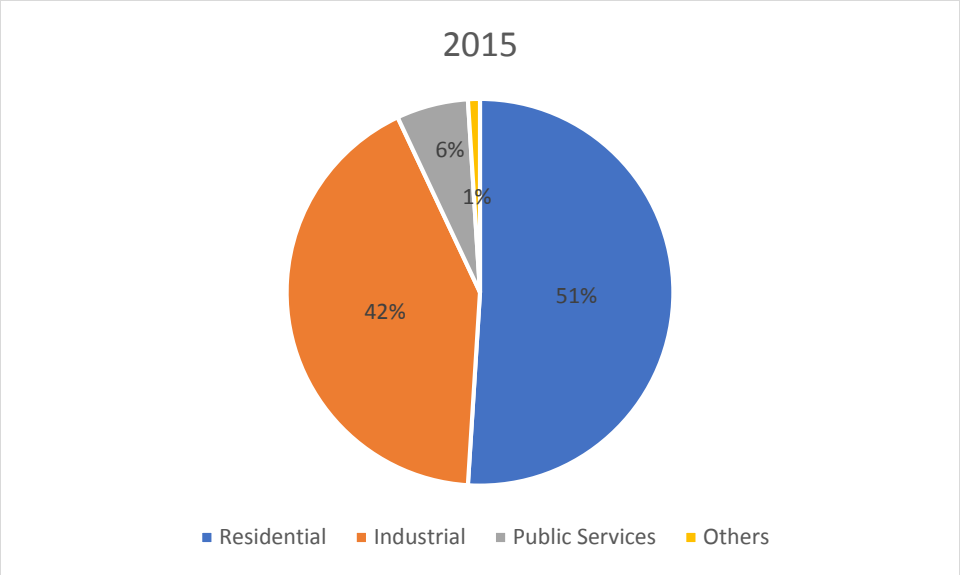

Figure 2.1: Percentage Electricity Consumption by Sector (Ministry of Infrastructure, 2015a)

The current electrification rate still low (30%), of which 27 % of the households are on-grid and 3 % off-grid power connected (REG, 2017). Some of the targets are getting achieved, now 100 percent of hospitals are electrified, 85 percent of health centers, 92 percent of administrative sector offices and 54 percent of primary and secondary schools (REG, 2017). The percentage of 70% households unconnected still a big number in Rwanda. The electrification rate per District [see Figure 2.2] indicate that a large number of households connected are in cities. From Map 1, we can classify the districts into three classes, first are the city with electrification rates between 50-75%, second,20-40%, and third 5-20%. The first categories are covered by the district in Kigali city, while the third cover the districts of the province which has the large portion of rural areas. Rwanda has 30 districts, of which 18 districts fall into the third category, 9 districts into the second category, and 3 districts into the first category. The large number in the third category implies the high percentage of households still use biomass especially wood fuels in these districts. Based on the country's target of achieving 70% electricity connected and reduction of biomass use to 50% by 2018 a lot needs to be done to achieve these percentage.

The percentage out of Kigali tend to increase because the electrification program is targeting these districts with a high number of households with no electricity access.

Among the barriers of electrification, the high cost of electricity also contributes in making the low percentage of electrification in rural areas, where most of the population are the low income. The electricity tariff as announced in (REG, 2016), shows the electricity tariff for all categories of customers and the cost value based on the electricity consumption per months. Rwfs 89/kWh(+VAT) is the least current cost of electricity, still high for the low-income residential customer who consumes between 0-15 kWh/month (See Appendix 1: Electricity tariff). This makes electricity no affordable for a large number of Rwandan people belong in the category of low-income households which presents high percentage.

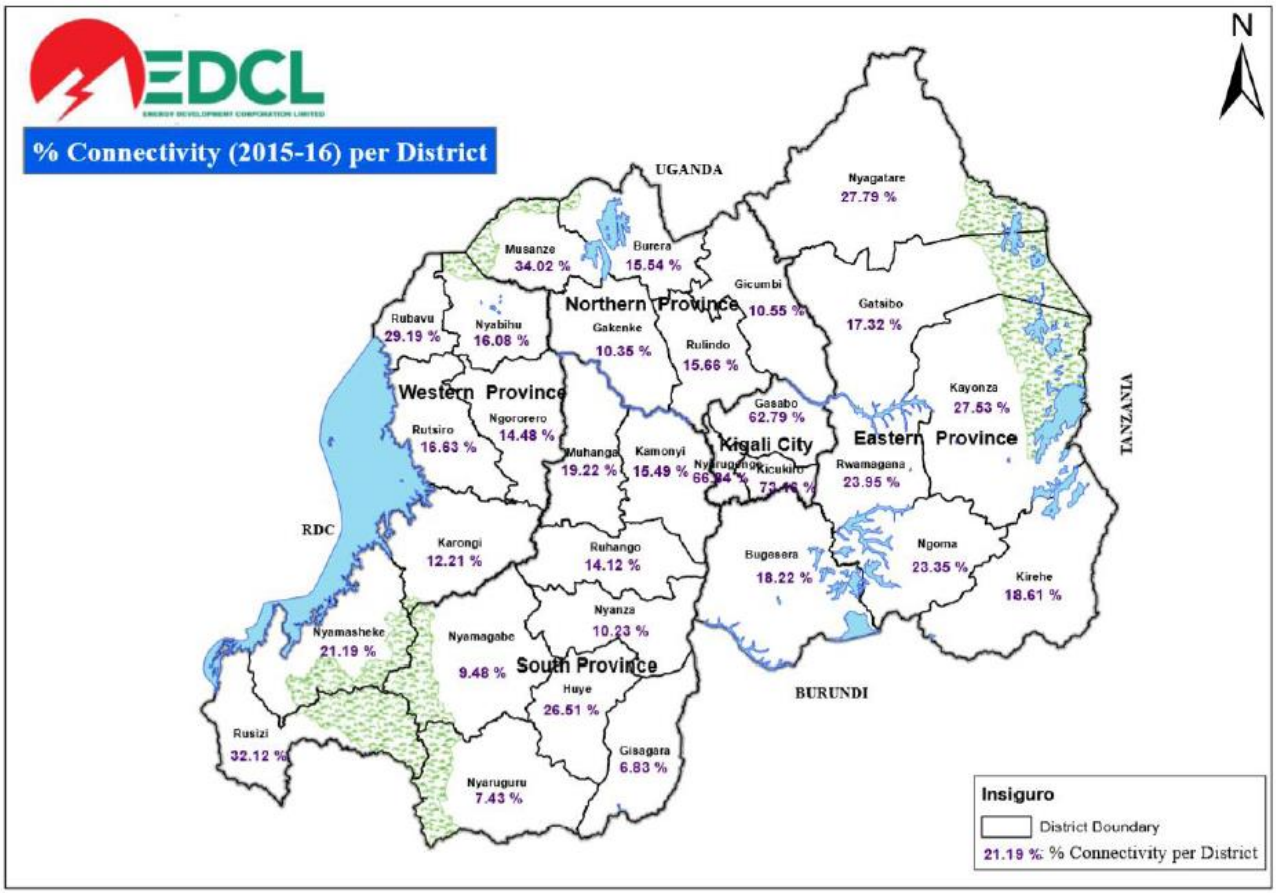

Figure 2.2: Map of National Grid Access Provision (source: EARP) **(Ministry of Infrastructure, 2016)**

The power generation is increasing dramatically from 95 MW (2010), 163.2 MW (2014) to 208.36 MW in 2017 and the country's target is to reach 563 MW by 2018 (REG, 2017). Based on this move, we can confirm that it is possible to achieve this target if the commitment to increase the generation keep increasing and large energy projects done.

Renewable energy resources hold a major part in Rwanda electricity generation (Safari, 2010). Hydropower among other sources remains the main contributor of installed capacity and it is likely to continue leading in next few years [see Table 2.1]. This is a result of energy importation mostly from renewable sources, particularly hydro and geothermal from neighboring countries such as Uganda and the Democratic Republic of Congo. Additionally, despite the possibility of achieving the 2020 vision, the current installed

capacity is not enough to satisfy the country's energy demands. However, one possibility of increasing the installed capacity can be through utilization of the country's available renewable energy sources. This can be achieved by sustainable implementation of the planned target strategies as indicated in Table 2.1.

Table 2.1 Power generation: Installed Capacity and Target Capacity (Ministry of Infrastructure, 2015c)

Types	*Resources potential (MW)*	*Current capacity 2015 (MW)*	*Target capacity by 2018*
Hydro	313–400	94	122
Solar PV	4.3–5.5 kWh/m^2/day	8	18
Geothermal	170–300	0	0
Import		4	94
Gas (methane)	350	4	79
Peat	700	0	145
Diesel		28	8
HFO		20	80
Total		*158*	*562*

Table 2.1 clearly indicates the country's energy status and planned target contribution by the different energy resources. Renewables are planned to highly contribute to Rwanda's future energy supply. Specifically, solar PV will possibly and considerably boost renewable installations by 2018. Currently, solar PV is one of the major energy source interesting the Government of Rwanda. The sector is being majorly promoted for both grid and off-grid purposes. Solar technology contribution is majorly targeted for electrification programs in health facilities, schools and administrative buildings (Ministry of Infrastructure, 2015c). Currently, energy from peat has not been given the required exploitation attention. However, peat energy generations are expected to contribute as much as 145 MW by 2018. Due to Rwanda's high energy expectation from the peat project, appropriate attention in terms of funds, capacity among others could be sought by the government. There is no plan for geothermal regardless its reliability and proved potential.

Having this high potential, it means a lot for the country which wants to boost her energy generation by promoting renewables.

2.2.1 Renewable Energy Resources in Rwanda

Rwanda's natural resources available including hydro, geothermal, solar, methane gas, biomass, peat, waste, and wind. Some of these resources and petroleum based fuels are used for electricity generation others remain untapped. However, the contribution of each resource in total energy generation varies depending on its maturity. Renewable energy sources play an important role in Rwanda total energy mix due to a large share of hydro in electricity generation [see Figure 2.3].

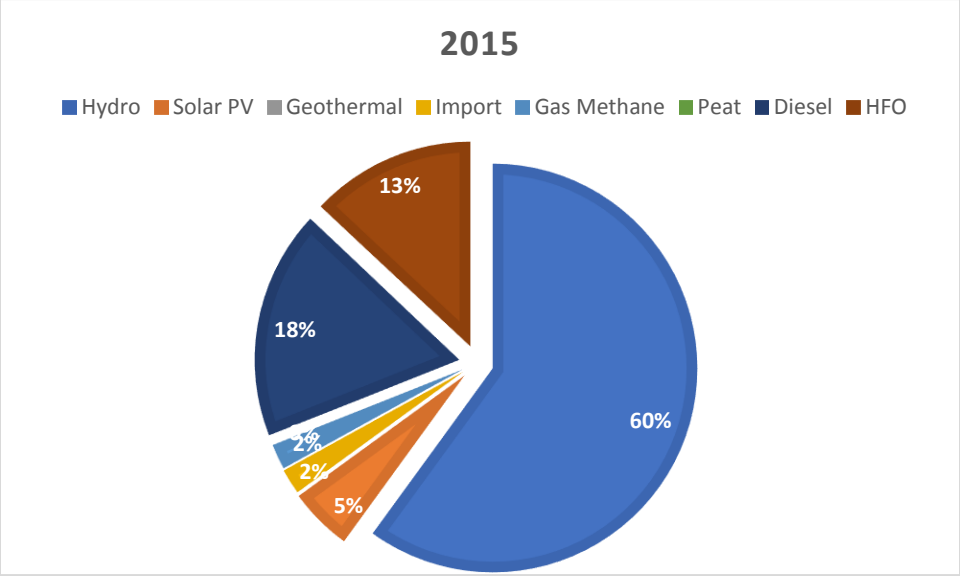

Figure 2.3: Percentage Energy Installed Capacity **(Ministry of Infrastructure, 2015a) (Ministry of Infrastucture, 2015b)**

Hydro followed by solar in the renewable energy sources highly used in Rwanda. Moreover, on imported energy mostly is from hydro. This still increases the role of renewables within the country. Diesel with 18% and Heavy Fuel Oil with 13% still large

percentage from non-renewable. This can only be reduced by diversifying in a generation or increasing the share of renewables.

Figure 2.4 below displays Rwanda renewable energy capacity by sources from 2006 to 2015. Hydropower has been a major contributing source for long period, while solar energy started appeared in the mix since 2014. Bioenergy does not present any share today to the grid. Still, hydro leads the renewables since the beginning. Two renewable energy sources are not the only available renewable source with potential within the country, as we have seen there are other sources with proven potential such as geothermal and wind. These sources need to be tapped. however, as the time moves, we believe that the percentage from these renewables will increase and boost the country generation. The indigenous renewables sources can change this image if the appropriate measures were taken.

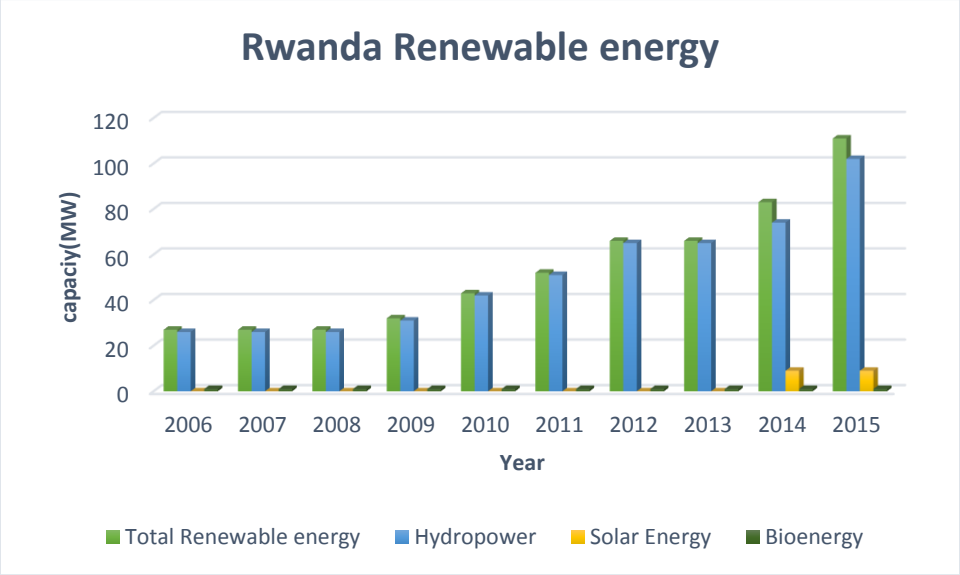

Figure 2.4 Renewable Energy Growth by Sources 2006-2015 **(IRENA, 2016)**

The growth in Rwanda total renewable power capacity is high from 27 MW in 2006 to 111 MW in 2015, i.e., 411% [Figure 2.5]. The renewable has increased times four only in 9 years. It is a good progress and shows country's commitment to increase the generation relying on renewables. This progress was in three periods; 2006-2008 with constant share,

2008-2012 they added 39 MW, and 2013-2015 additional was 45 MW. The third phase was highly boosted by the share of solar. Keep moving with this speed it can change a lot in the energy sector.

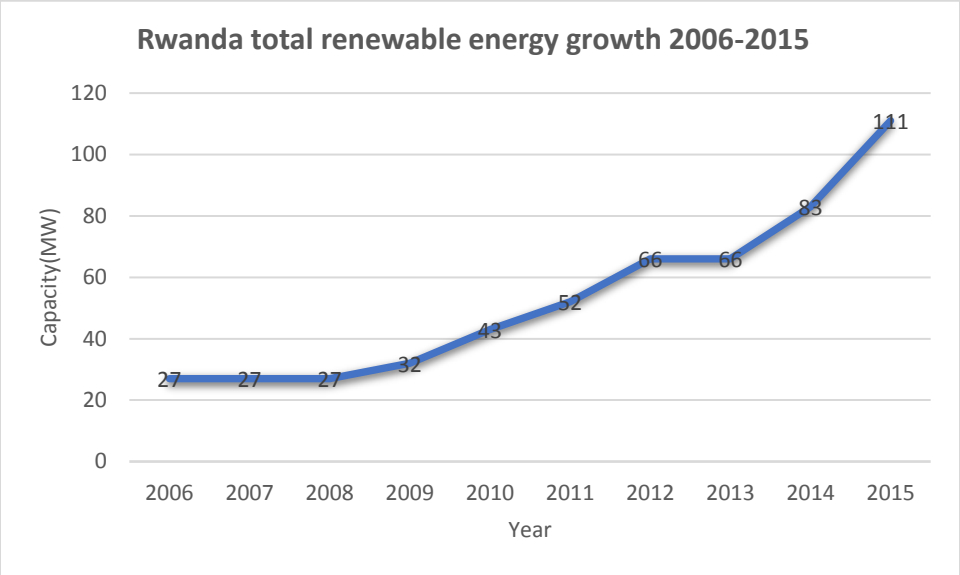

Figure 2.5: Rwanda Total Renewable Energy Growth 2006 – 2015 **(IRENA, 2016)**

2.2.1.1 Hydro

Despite the fact that Rwanda is among the Africa's smallest country with 26338 km^2 in area, it has 861 rivers and 101 lakes (Aboniyo, et al., 2017) (REMA, 2015). Based on the river where water drains into, Rwanda's water lies into two main hydrological basins; Congo and Nile River basins. Figure 2.6 shows Rwanda's major rivers and lakes across the country. They are being used for micro, mini, small, medium, and large hydropower plants for both on/off-grid purpose. A total of 333 scattered sites across the country has confirmed potentially to support these hydro power plants categories.

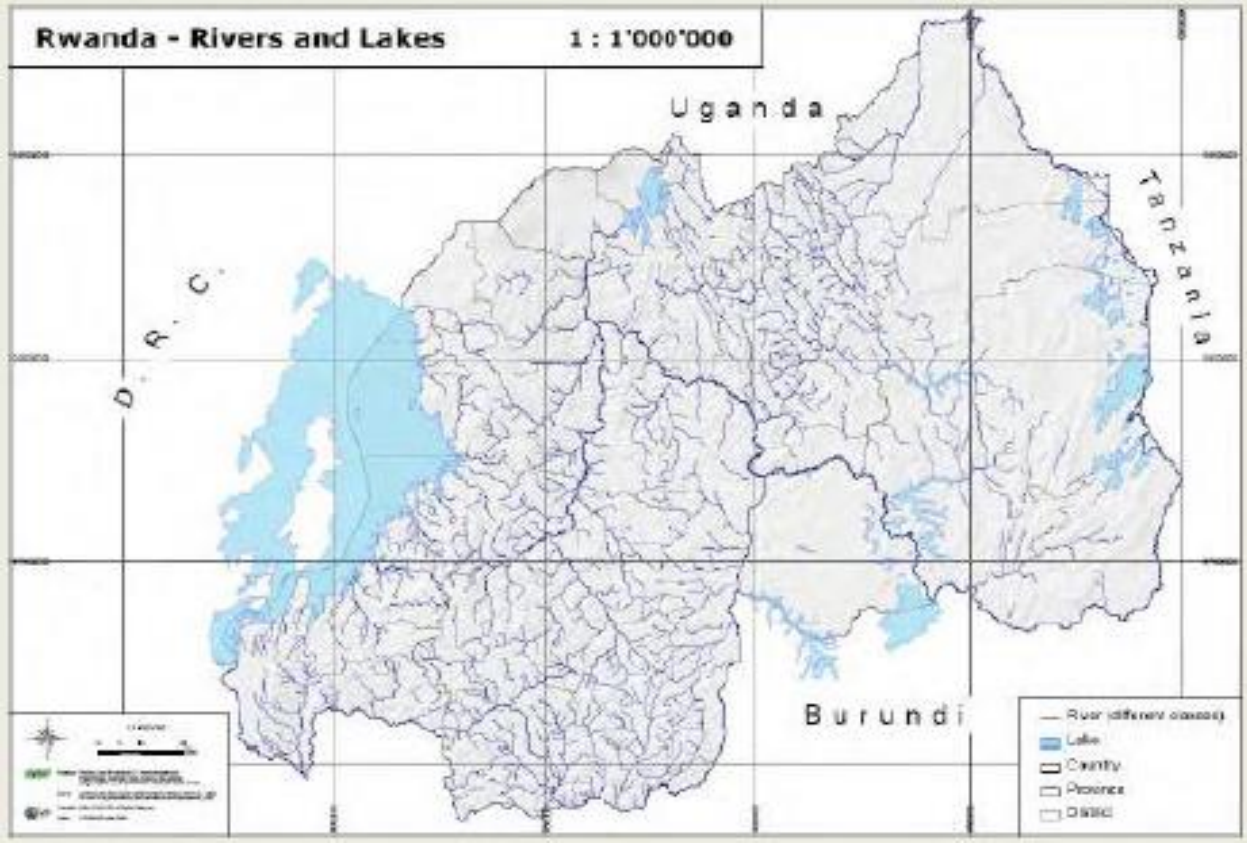

Figure 2.6: Map of Rwanda Rivers and Lakes **(Ministry of Infrastructure, 2016)**

In Rwanda, Hydro leads other renewable energy sources to be deployed in energy generation. Currently, it is being used for both On-grid and off-grid purpose. In addition to domestic Hydro installed capacity, Rwanda also imports electricity from hydro region projects of neighboring countries.

The current major hydro projects within the country include (EDCL, 2017):

- ✓ Mukungwa I with 12 MW installed capacity
- ✓ Ntaruka with 11.25 MW installed capacity
- ✓ Nyabarongo I with 28 MW installed capacity
- ✓ Rukarara I with 9 MW installed capacity

The rest domestic hydro projects contribute to the grid with the low installed capacity ranging between 0.1MW to 5 MW each. A Total of 1140 kW is being generated from off

grid micro hydro power plants (Nyamyotsi I 100 kW, Agatobwe 200 kW, Nyamyotsi II 100 kW, Rushaki 40 kW, Nyirabuhombohombo 500kW and Gashashi 200kW).

The region projects allow Rwanda to import about 15.5 MW from Rusizi I and II, with 3.5 MW and 12 MW respectively. This quantity will increase due to the planned local and regional hydro projects.

What has been said so far actually shows how hydro plays a major role in Rwanda electricity production. It contributes more than 50% in electricity generation [see Figure 2.3], it has subjected that, it is because of its mature and low operational costs comparing to another form of energy sources. The hydro contribution in total electricity generation still dominate and will remain as the projects in place are targeting the use of hydropower plant for boosting energy generation. Hydro and solar are highly targeted for mini-grid in current electrification program. This still raises the value of hydro in Rwanda energy sector.

2.2.1.2 Solar

Among the renewable energy sources available in Rwanda, Solar is one of the renewable energy sources which have the potential to some extent. Across the country, the annual daily mean global solar radiation is about 5.2 kWh/m^2/day (Safari, 2010) and this proven solar as an opportunity for both On-grid and off-grid purpose. Currently, the large solar project in Rwanda is Gigawatt Global project feeding into the grid with 8.5 MW. The plant commissioned in 2015 with support from different partners include Netherlands, Norway, Australia, London-based and United States government (Gigawatt Global, 2015). The Gigawatt Global project is located in Rwamagana at Agahozo-Shalom Youth Village. Due to unavailability of updated data, it is hard to quantify the total contribution from solar off-grid projects. However, we know that it presents large share as currently being used in electrification program.

Because of high initial cost, solar systems are not widely used in Rwanda. Though, the renewable energy technology based on solar systems and mini- grids have high advantages in Rwanda. Under EARP program, the use of the Solar home system (SHS) is highly

appreciated in electrification process for the remote areas. There is a lot of funds and support from the government to promote solar home systems and solar water heaters across the country. There is a high expectation in relying on off-grids solutions to increase electricity access.

Obviously, Solar has potential in Rwanda as it is presented in Figure 2.7 below. The Map reveals that the large part of Rwanda has good solar potential. Furthermore, both the global horizontal irradiation [Figure 2.7 (a)] and direct normal irradiation [Figure 2.7 (b)] recorded in South, Kigali City, and Eastern Province indicate the good potential of solar in these regions. The average annual sum of Global horizontal irradiation in these three regions varies between 1800 kWh/m^2 and above 2000 kWh/m^2 , and direct normal irradiation between 1200kWh/m^2 and above 1400 kWh/m^2 . These quantities are good and enough to the extent that they can be used for different solar projects. What needed is just to recognize this abundance available solar quantity and harnessed.

(a) (b)

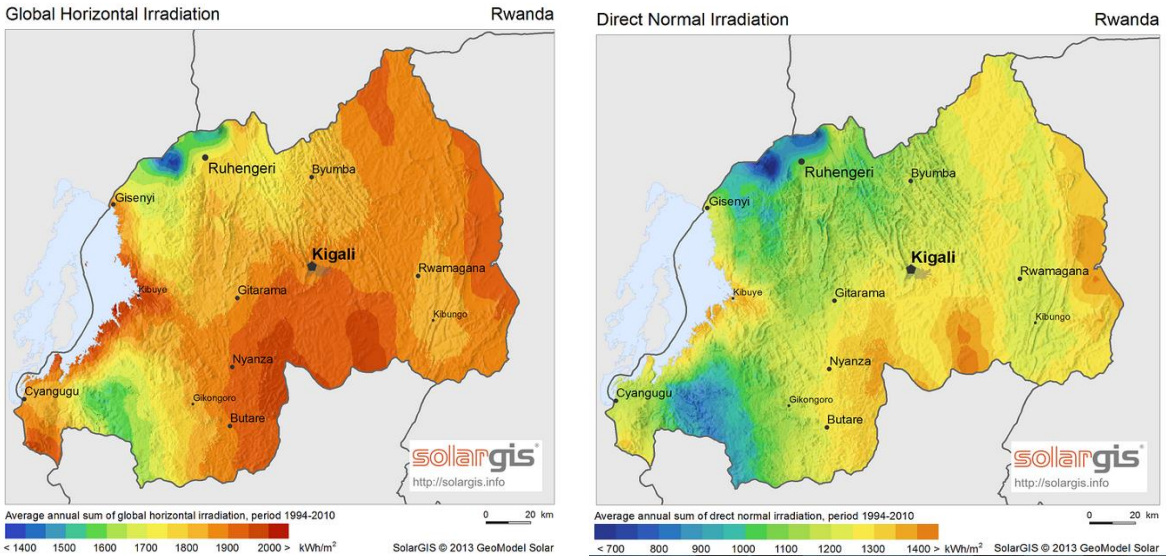

Figure 2.7: Rwanda Solar Map **(Solargis, 2013)**

Depending on the potential available in the regions, the country provides the Figure 2.8 below illustrates country's priority in promoting solar use, it is based on the availability of

intense solar radiation in the region. Across the country, eastern region has high intensity of solar radiation compared to other regions, that is why it is the first priority in the Map below. Kigali city and southern region follow with the second priority and West and Northern took the last PV priority across the country.

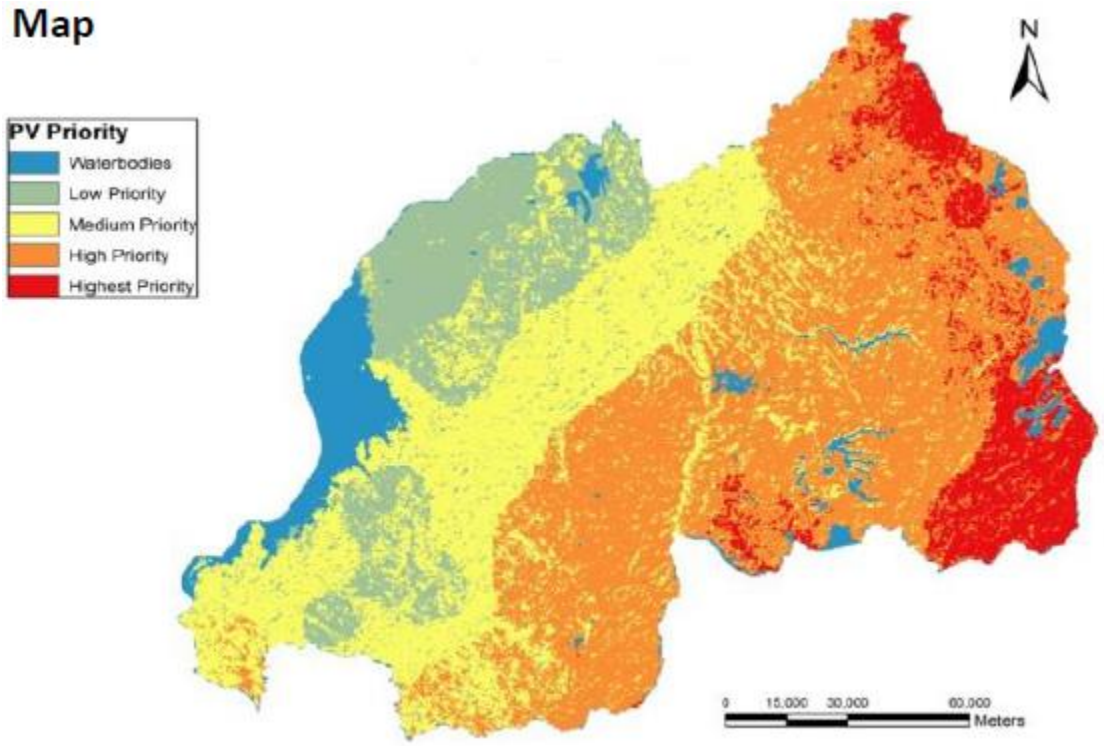

Figure 2.8: Map of Country's Solar Priority (NASA 'Rwanda Agriculture & Energy' (2013))

2.2.1.3 Biomass

Rwanda like most of the East African countries, biomass energy still serves a large number of households for cooking (IRENA, 2015a). The form of biomass available in Rwanda ranges from firewood, charcoal, biogas, and biofuels. As reported by AESG (Africa Energy Services Group LTD Rwanda, 2012) in 2012, biomass production within Rwanda was not meeting the demand. The annual biomass supply stood at 2905520 m^3 while the total annual biomass consumption was 6792674 m^3 signposting a deficit of 3887154 m^3. In addition to this, the smoke related to inefficient use of biomass-based energies is responsible for some respiratory diseases and death in Rwanda (Ministry of Infrastructure, 2015a).

The use of biomass still at a high level regardless these challenges. In 2015, biomass contributed with 85% of total energy use (Ministry of Infrastructure, 2015a). The number tends to decrease where the country's plan is to reduce it from 85% to 50% by 2018 (Ituze, et al., 2017). Through the National Domestic Biogas Program (NDBP), the government is highly expecting the reduction of woodfuels by promoting Biogas. however, they need to keep in mind that the successful use of biogas energy technology requires more innovations to improve cost-effectiveness and resource efficiency (Budzianowski, 2016). More to this, three major strategies highlighted to be used to achieve this target includes:

- ✓ Promoting the use of alternative fuels (Peat, LPG, Biogas)
- ✓ Increasing the efficiency of charcoaling technologies and improved cook stoves (ex, Canarumwe, Tekavuba); and
- ✓ Improving the production and distribution of wood fuels (SNV, 2015).

A Large percentage of the people who rely on biomass live in rural areas and there are also categorized as the low-income people. Due to the high cost of electricity, Peat, LPG, Biogas and low-income capacity of Rwandese with low GDP per capita of US $643 (Ituze, et al., 2017), sidestepping biomass, it is not an easy task to achieve within this remaining time. To meet this goal, it requires high investment on both side government and citizen. Reduction of fuelwood use has the advantage to reduce carbon emissions.

2.2.1.4 Geothermal

Geothermal energy is the energy generated from the heat enclosed within the earth's core (Melikoglu, 2017). The use of this form of energy is mainly divided into two categories: electricity generation and direct application (Irfan, et al., 2017). Geothermal is among the energy sources which have a considerable potential within Rwanda, ranges between 170-300 MW as reported by Geothermal Energy Association (Safari, 2010). Despite the fact that geothermal has this great potential, most Rwandan's energy comes from other sources excludes geothermal. Currently, this technology has given less attention, whereby it does not present any share in energy generation. None of its application is being used for.

The partnership of Rwanda government with the international agencies was able to identify four areas with high geothermal potential; Kalisimbi, Kinigi, Gisenyi in northwestern region and Bugarama in the southwestern region of Rwanda [see Figure 2.9] (JICA, 2016) (Uwera, 2015). As As a member of East African region, Rwanda is a riparian of Rift Valley country, and this approves her potential for geothermal energy (IRENA, 2015a). More to that, the further study on geothermal exploration and development to these locations are currently going on and requires high investment.

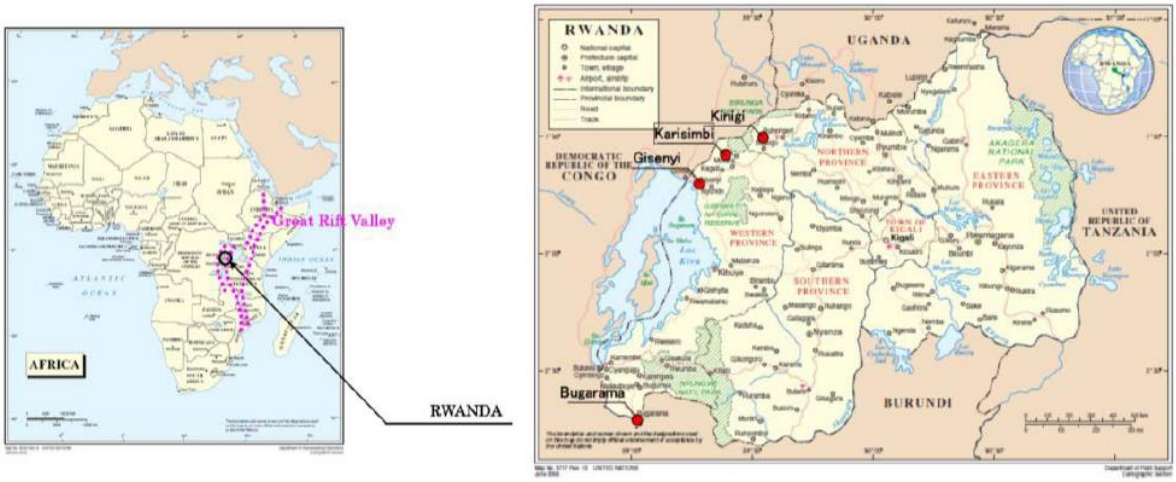

Figure 2.9: Map of Geothermal Potential Areas in Rwanda **(West Japan Engineering Consultants, et al., 2014)**

2.2.1.5 Wind

Wind energy is the best renewable energy source option for power generation and other application where it is applicable. The technology requires harnessing the power in wind still highly cost and are not easily available compared to other technology. The availability of required wind speed also is a challenge in wind energy use. The wind technology seems to be new technology in Rwanda energy sector. Currently, there are only two available wind projects countrywide.

- ✓ Wind turbine project was at Mont Karisimbi to power the National Radio and Television antenna,

- ✓ Wind turbine at Gabiro district for water pumping purpose.

Wind potential available in Rwanda depends on annual season (dry and rainy) and regions. During the dry season, the western region meets up a wind speed of ≥ 4.5 m/s at 60 m above the ground while the wind speed in the rainy season, the Center and Southern meet the same ≥ 4.5 m/s at 60 m above the ground (Safari & Gasore, 2010). It is relatively high. Currently, there is no wind energy contribution into grid connection within Rwanda. With this average wind speed, this source is a good option to go but requires deep analysis. The Wind can boost energy in a combination with other renewables sources. At 10 m above the ground, Wind speed does not look favorable for energy generation. In most available documents, wind speed considered is at 10 m height which confirms low potential in most case. By taking a decision based only on this it is a wrong position and this makes wind sources not exploited. Further research needs to be conducted to ensure the potential at different heights in different locations. That is why in our research we adjusted heights from 10m up to 150m. The current energy policy did not consider the wind as an option due to the fact it, in its formulation they did not base on further research for this energy sources. That is why we do not see any wind project to boost future energy generation. Wind energy source needs to be given attention because it has potential to sustain energy generation and country's development.

2.3 Energy Policy of Rwanda

The policy is a framework developed to guide a process. Energy is an engine of transformation tackles all the sectors ranging from education, health, transport, tourism, ICT, construction, manufacturing, mining, to agro-processing. Rwanda energy sectors are one of the leading sectors need more attention due to its significant role in country's economic transformation and target achievement toward vision 2020.

Rwanda energy policy has been developed with aim of guiding and influencing decisions related to extraction, development, and use of Rwanda's energy resources (Ministry of

Infrastructure, 2015a), in a way that energy sector can impact other sectors positively toward country's development and socio-economic transformation.

Vision

Rwanda energy sector has the vision to contribute meaningfully to country's economic growth while improving the citizen's standard of living in a sustainable and eco-friendly way.

Mission

The energy sector has a mission to address energy trilemma (Energy Security, Energy Equity, and Environmental Sustainability) across the country.

Overarching Goals

The main goal of this energy policy is to ensure a safe delivery of energy products and services to all Rwandan equitably and to domestic industries.

Objectives

Rwanda energy policy objects to ensure: energy security and energy equity, the participation of private sector in the energy sector (production and service delivery), energy efficiency, sustainability of energy-related activity and availability of adequate institutional, organizational, and qualified people.

Key Policy Principles and Priorities

1) Building decentralized energy policy implementation capacity through empowering the local stakeholders (Rwandese, Organisational, Companies, and Institutional)

2) Promote value for money and increased market competition in energy development through the increase of private sector participation in energy projects and services as well as promoting transparency.
3) Promote “smart subsidies” for all energy-related interventions in order to ensure affordability of energy services to most vulnerable Rwandan group.
4) Private operation of government-owned power plants, both government and private sector incorporated in operation and management of these power plants.
5) Promoting private sector participation by facilitating them in all stage of energy projects

Chapter 3. RESULTS AND DISCUSSION

3.1 Hydro

Due to different factors, which are not mentioned, it has been reported by EDCL, that water in rivers and lakes are decreasing. One of the major river Ntaruka with the plant contributing to the grid with 11.25 MW is witnessing the reduction of water flow and this affects electricity production. We can guess that the cause of this is climate change or the agriculture activities around the river, that is why further research is recommended on this issue. Furthermore, for a country like Rwanda, which highly relies on hydro in electricity generation this variation in water flow will affect the achievement of energy reliability and security. Based on this, it is highly needed to promote diversification in energy generation in order to address this challenge and ensure energy delivery in a sustainable manner.

Rwanda has 861 rivers and 101 lakes (Aboniyo, et al., 2017) (REMA, 2015). Most of them, they are being used for micro, mini, small, medium, and large hydropower plants for both on/off-grid purpose. A total of 333 scattered sites across the country has confirmed potentially to support these hydro power plants categories.

Hydropower is susceptible to climate change effect due to the fact that it is sensitive to the amount, timing, and geographical patterns of precipitations and temperature (Ministry of Infrastructure, 2015a). Based on this, it is best to find a way of deploying other renewable energy sources in energy generation. This will not only help county secure energy production but may also avoid some conflict on the demand side and sustain economic development as well as reducing gases emission from non-renewable energy sources deployment. Most of the available energy projects to increase generation are highly targeting Hydro power. In the planned local projects, there are Rukarara V(5 MW), Rukarara VI(6.8 MW), Giciye III(6.7 MW) and Ntaruka A (2 MW). The region hydro

projects still expected to contribute a lot in energy generation. There is Rusumo Project with 80MW and it is a shared project between Burundi, Rwanda, and Tanzania. Another large project is Rusizi III with 147 MW and it is between Burundi, Congo, and Rwanda. By 2020 all these projects will be in operation as planned if there is no disrupts. This confirms how Hydro will continue to dominate the other renewable energy sources in power supply, which is not bad but also the need to value the other indigenous renewable resources is an advantage.

3.2 Solar

In 2007, the Rwanda monthly average global solar radiation was estimated to vary between 4.3 and 5.2 kWh per meter squared per day (Ministry of Infrastucture, 2015b). However, our findings from the analyzed locations are different from the above country estimated value of global solar radiation. Furthermore, the data analyses provide the information of five locations; Nyagatare, Ruhengeri, Kanombe, Byumba, and Butare. This study used the data of only one the year 2015 for solar radiation which recorded after 10 minutes every day from 05:00 AM to 18:00 PM.

What has been found so far in Table 3.1 below, it indicates different potential from January up to December 2015. In this work, we assume that in these locations the Sunrise and Sunset times are 05:00 AM, and 18:00 PM respectively. In the five locations we studied, the solar potential is relatively good. The solar radiation increased as the day grows, this implies that at any day time you can receive some amount which can serve you for different applications. In the whole year, the peak Sun hours can approximately be five hours range from 11h to 15h per day. During this period, it is where the maximum radiation can be harvested in most location. Even if there is available radiation the whole years, from June up to October the yield increases as there is high solar intensity. In All the locations, the Sun is available in all the period of there is not a deficiency for solar radiation. This still stresses how solar it is a good option to support the country energy supply. The available radiation can serve for electricity generation, Water heating, Battery charging and other

purposes. Even if the further study can accurately confirm the availability potential (Wh/m^2) of solar in these locations, what we presented so far gives hope of the good results.

Table 3.1 Hourly Average Solar Radiation Wh/m^2

NYAGATARE

Time	January	February	March	April	May	June	July	August	September	October	November	December
5h	0.4	0.3	2.4	0.2	0.2	3.7	7.8	53.7	0.7	2.3	12.3	13.4
6h	50.1	28.4	92.8	74.2	87.5	143.5	191.8	327.3	107.8	128.9	199.2	185.0
7h	319.0	260.5	271.0	336.4	352.6	472.1	545.5	710.8	517.5	493.4	523.8	669.5
8h	718.0	609.3	668.7	694.6	779.8	792.6	928.6	1099.9	968.4	915.5	948.2	1029.2
9h	1051.2	996.3	908.0	939.0	1066.8	1115.8	1271.5	1290.6	1327.6	1273.0	1240.9	1424.5
10h	1346.3	1227.1	1220.4	1146.6	1144.3	1277.9	1456.5	1394.5	1444.1	1486.0	1371.4	1583.2
11h	1444.0	1394.7	1384.1	1352.7	1329.7	1237.6	1440.0	1369.1	1445.2	1490.2	1207.3	1373.3
12h	1283.2	1234.6	1125.4	1374.9	1258.7	1089.6	1253.8	1254.2	1287.4	1157.3	1113.0	1279.4
13h	1066.4	1176.2	1234.6	1202.0	968.9	1003.9	1013.6	920.0	1023.5	1164.2	1093.6	1066.4
14h	982.1	987.8	998.3	933.6	739.9	744.3	765.2	659.5	719.5	936.7	756.9	948.6
15h	730.9	691.8	633.5	659.5	573.5	545.3	499.0	409.5	425.3	640.1	488.5	650.4
16h	416.0	424.1	409.8	407.1	386.5	278.9	234.4	144.9	211.9	350.7	246.1	313.8
17h	139.4	192.3	112.3	108.5	97.3	43.7	37.1	11.2	63.2	86.5	40.4	67.7
18h	10.2	17.1	3.7	2.5	0.9	0.0	0.0	0.0	0.6	0.9	0.3	1.5

RUHENGERI

Time	January	February	March	April	May	June	July	August	September	October	November	December
5h	0.11	0.03	0.11	31.48	0.19	0.00	0.03	0.06	2.10	2.35	2.60	0.29
6h	81.54	94.49	103.90	435.33	160.48	105.53	94.45	116.45	296.13	261.61	278.23	215.74
7h	664.66	780.54	674.82	1136.26	734.23	700.57	698.77	797.19	1144.10	1113.61	1112.30	1007.03
8h	1668.27	1795.05	1511.39	2135.94	1475.48	1425.57	1623.81	1751.26	2348.73	2060.90	2069.87	2133.84

9h	2832.80	2947.48	2424.39	2791.54	2345.26	2356.07	2649.26	2825.06	3494.80	2920.42	2966.43	3222.65
10h	3895.46	3888.38	3219.99	3250.43	2720.23	2917.60	3452.68	3746.06	4105.40	3376.39	3336.40	3955.52
11h	4097.46	3952.34	3547.94	3540.56	2887.32	2730.53	3920.32	4030.10	3781.43	2903.84	3479.30	3559.23
12h	3409.36	3635.25	3831.44	3711.21	3371.16	2943.77	4007.77	3937.00	3213.00	2787.87	3392.63	3437.55
13h	3012.22	3209.68	3646.62	2789.23	2776.81	2710.03	3520.90	3390.52	3082.13	2626.65	3061.23	3113.48
14h	2422.70	2709.94	3024.85	2070.94	2568.39	2105.30	2812.26	2759.45	2360.53	1636.94	2073.70	2669.71
15h	1813.23	2095.97	2376.16	1238.96	1507.13	1425.53	1961.84	1839.77	1368.90	1455.87	1273.60	1874.61
16h	1232.68	1172.73	1126.55	525.01	875.90	827.57	1163.94	959.39	742.07	767.29	787.53	860.26
17h	445.27	392.99	376.13	66.75	166.29	202.60	315.84	264.06	118.13	157.39	171.43	281.77
18h	34.83	19.86	11.00	1.09	0.00	0.73	3.16	1.71	0.03	0.16	0.13	2.74

KANOMBE

Time	January	February	March	April	May	June	July	August	September	October	November	December
5h	77.41	79.14	77.75	77.56	77.60	77.89	77.99	77.46	78.10	84.23	77.74	77.42
6h	221.21	224.42	79.15	269.35	229.94	220.58	189.64	196.14	292.73	482.32	114.49	79.87
7h	935.99	800.66	241.56	999.52	858.41	943.11	918.04	847.64	1120.14	1413.12	443.67	366.04
8h	2031.34	1726.68	1032.03	1817.69	1838.55	1871.55	2014.95	1742.84	2168.37	2551.81	1240.17	1143.55
9h	3090.58	2735.09	2089.03	2788.48	2896.25	2859.16	3270.23	2926.14	3375.26	3853.43	2261.64	2256.62
10h	3990.35	3469.64	2756.69	3764.30	3541.28	3617.59	4099.29	3861.78	4038.27	4361.26	3043.45	3208.92
11h	3962.04	3885.20	3576.96	4016.88	3889.69	4028.82	4641.71	3866.94	4107.78	4347.26	3621.05	3970.98
12h	3811.97	4215.05	4116.00	4222.09	3308.94	3761.35	4581.14	3657.25	3845.10	4109.72	4145.34	4049.98
13h	3172.24	3821.44	4323.49	3887.45	3377.98	3399.84	4148.64	3546.48	3591.47	3808.57	3978.05	4093.52
14h	2769.95	2663.27	3646.71	2914.11	2814.62	2897.70	3559.49	3278.72	2683.45	2685.86	2889.35	3733.81
15h	2105.60	1702.42	3171.67	2329.66	2365.50	2152.54	2482.75	2361.42	2018.20	1862.72	2153.02	3067.53
16h	1083.17	967.18	2652.56	1289.60	1237.55	1131.18	1405.08	1257.08	1002.32	959.35	1570.59	2239.84
17h	375.04	319.98	1385.75	309.54	404.15	279.91	362.32	324.51	235.84	195.96	883.61	1110.88

18h	80.28	80.59	419.46	78.96	83.23	78.29	79.05	78.80	78.16	78.00	213.94	265.51

BYUMBA

Time	January	February	March	April	May	June	July	August	September	October	November	December
5h	0.49	0.36	0.44	0.83	0.82	0.42	0.41	0.42	0.90	2.42	1.49	1.43
6h	55.77	40.65	60.34	78.09	61.13	38.17	38.27	32.67	69.07	123.16	80.85	62.51
7h	256.42	241.85	289.77	287.70	239.52	237.19	254.99	190.13	284.57	383.57	281.75	223.89
8h	470.81	436.03	469.15	461.26	392.47	470.40	530.54	445.64	497.34	640.34	449.64	678.53
9h	567.52	598.92	586.98	694.75	577.40	719.33	802.27	759.53	676.60	783.10	563.17	611.89
10h	841.98	707.97	696.09	884.10	808.95	980.69	1125.28	951.03	814.00	734.13	812.67	916.64
11h	1183.54	954.90	748.23	992.92	938.04	1133.03	1239.09	962.13	901.99	994.05	1060.06	1117.68
12h	1102.68	1000.34	1067.30	976.76	915.50	1027.09	1204.62	935.72	976.10	1051.21	1174.77	962.45
13h	1029.61	884.80	996.86	913.04	959.62	999.66	1043.15	960.86	852.67	1067.37	957.98	988.49
14h	845.81	688.58	895.80	894.86	762.82	723.26	801.27	786.29	744.18	734.41	721.77	827.10
15h	615.25	456.05	698.18	641.71	522.63	536.84	599.91	616.90	499.60	512.44	503.51	546.09
16h	317.91	269.75	393.54	388.02	295.62	279.39	362.82	334.25	303.72	288.49	286.45	219.96
17h	142.12	104.02	137.41	103.21	79.61	95.91	118.54	96.65	84.28	68.89	86.30	90.64
18h	5.43	6.10	4.63	1.14	1.25	1.94	3.89	3.52	1.26	0.61	3.70	6.53

BUTARE

Time	January	February	March	April	May	June	July	August	September	October	November	December
5h	1.1	5.5	0.1	0.4	0.8	0.4	0.2	0.2	0.4	3.9	4.3	1.0
6h	305.1	264.9	192.0	248.7	245.1	101.6	108.1	111.0	212.6	425.4	315.7	274.7
7h	1333.9	1082.5	1096.7	1196.3	979.1	685.8	842.2	833.7	1050.2	1397.4	1171.3	1203.9
8h	2502.6	2061.1	2203.7	2329.4	1956.2	1710.8	1975.3	1842.2	2141.7	2715.0	2195.5	2365.8
9h	3477.9	2760.3	3471.6	3288.3	2785.8	2780.1	3128.2	2693.3	3125.7	3840.0	3046.6	3160.5
10h	4075.3	3535.6	3849.4	3975.6	3194.9	3532.9	4103.3	3556.8	4076.4	4285.4	3616.4	3444.0

11h	3147.7	3480.7	4041.2	4100.7	3489.9	3626.0	4732.7	3876.8	3964.9	4130.8	2856.9	2967.3
12h	2918.4	3121.7	4312.9	4075.2	3369.2	3674.5	4643.5	3686.3	4133.7	4108.9	3167.4	2735.9
13h	3607.3	2972.2	4342.8	3685.8	3430.1	3448.4	4012.1	3500.3	3759.1	3852.0	3493.9	3789.1
14h	2705.7	1983.2	3497.0	3104.8	2665.3	2979.1	3296.8	2831.9	3205.4	3143.2	2769.9	2889.1
15h	1901.0	1402.1	2459.7	2518.3	2287.2	2223.9	2390.9	2031.5	2096.6	2130.1	1781.3	2110.5
16h	984.3	741.2	1457.3	1191.6	1297.8	1201.2	1387.6	1069.4	1089.4	984.2	896.2	1004.6
17h	269.0	194.5	349.4	321.5	262.7	321.3	374.2	290.0	274.7	167.8	213.2	250.6
18h	1.7	1.9	5.8	0.2	0.8	1.4	3.9	2.5	0.4	0.2	0.3	3.9

3.3 Wind

We normally know that wind speed changes according to tower height. More you go high, more wind speed you gain and more specific power in the wind you get. In our work, we used power law method [formula 1] to estimate wind speed at the height of 10 m, 30 m, 50 m and 150 m above the ground.

$$\frac{V}{V_o} = \left(\frac{h}{h_o}\right)^n \qquad (1)$$

Where V is the wind speed at height h, V_o is the wind speed at height h_o (in this work we used 10 m as our reference height h_o) and n is the power law exponent which depend on the surface over which the wind blows (in this work we used n= 0.143).

We were able to observe that at Kanombe station wind is relatively high among the studied locations, its average wind speed falls into a range of between 3.6 m/s at 10 m and 5.3m/s at 150m [see table 3.2]. In this location, the average wind speed reaches even 7 m/s in January, February, August, and September. This station can be used to generate energy and connected to the grid, due to the fact that 5m/s is favorable for grid-connected applications. The remaining four locations at this height of 10m-150m the wind speed is very weak to any applications it falls between 1.0m/s and 2m/s respectively. And this is not favorable

even for battery charging or water pumping which requires 3-4m/s. The last station is Nyagatare where the wind speed is between 1.09m/s at 10m and 1.6m/s at 150m. If in these five locations analyzed we were able to find one favorable location, there is a high possibility to find other locations if further research conducted across the country. The energy policy in place does not talk about wind energy in Rwanda, it only reveals that there is no potential for the wind in Rwanda which is different from what we observed. This back to the gap in policy formulation which did not base on further research and expert consultation about the potential of all indigenous resources.

Table 3.2 Average Wind Speed

Location		10 m (h_o)	30 m	50 m	150 m
Nyagatare	January	0	0	0	0
	February	0	0	0	0
	March	1.1293	1.3215	1.4216	1.6634
	April	1.3364	1.5637	1.6822	1.9684
	May	1.7789	2.0815	2.2392	2.6202
	June	1.7402	2.0362	2.1905	2.5632
	July	1.8883	2.2096	2.377	2.7814
	August	2.0465	2.3946	2.5761	3.0143
	September	1.7563	2.0551	2.2108	2.5869
	October	0	0	0	0
	November	0	0	0	0
	December	1.4756	1.7266	1.8575	2.1735
Annual average		**1.096**	**1.2824**	**1.3796**	**1.6143**
Ruhengeri	January	1.8852	2.2059	2.3731	2.7768
	February	1.8172	2.1263	2.2874	2.6766
	March	1.6591	1.9413	2.0885	2.4437
	April	1.4289	1.672	1.7987	2.1047
	May	1.3549	1.5854	1.7055	1.9957
	June	1.4744	1.7252	1.8559	2.1716
	July	1.8125	2.1209	2.2816	2.6697

	August	1.8911	2.2128	2.3805	2.7855
	September	1.7412	2.0374	2.1918	2.5646
	October	1.5131	1.7704	1.9046	2.2286
	November	1.4792	1.7308	1.862	2.1787
	December	1.5968	1.8684	2.01	2.352
Annual average		**1.6378**	**1.9164**	**2.0616**	**2.4124**
Kanombe	January	4.9226	5.76	6.1965	7.2506
	February	6.2913	7.3616	7.9194	9.2667
	March	2.2283	2.6074	2.805	3.2822
	April	3.3961	3.9738	4.2749	5.0021
	May	2.9424	3.4429	3.7038	4.3339
	June	2.8915	3.3834	3.6398	4.259
	July	3.3606	3.9323	4.2303	4.9499
	August	4.7484	5.5561	5.9772	6.994
	September	5.1486	6.0245	6.481	7.5835
	October	2.2821	2.6703	2.8727	3.3613
	November	2.48	2.9019	3.1219	3.6529
	December	2.5731	3.0109	3.239	3.79
Annual average		**3.6054**	**4.2188**	**4.5385**	**5.3105**
Byumba	January	2.302	2.6936	2.8978	3.3907
	February	1.838	2.1507	2.3136	2.7072
	March	1.7987	2.1047	2.2642	2.6494
	April	1.8269	2.1377	2.2997	2.6909
	May	2.1936	2.5668	2.7613	3.231
	June	1.9945	2.3338	2.5106	2.9377
	July	2.0646	2.4158	2.5989	3.041
	August	1.7953	2.1007	2.2599	2.6443
	September	1.6965	1.9851	2.1356	2.4989
	October	1.7263	2.02	2.173	2.5427
	November	1.8796	2.1994	2.3661	2.7686
	December	2.2397	2.6207	2.8193	3.2989
Annual average		**1.9463**	**2.2774**	**2.45**	**2.8668**

Butare	January	1.9548	2.2873	2.4606	2.8792
	February	1.92	2.2466	2.4168	2.828
	March	1.9605	2.2936	2.4674	2.8872
	April	1.865	2.1823	2.3477	2.747
	May	1.7642	2.0643	2.2207	2.5985
	June	1.741	2.0372	2.1916	2.5644
	July	1.872	2.1904	2.3564	2.7573
	August	1.8835	2.2039	2.3709	2.7742
	September	1.9461	2.2771	2.4497	2.8664
	October	1.9611	2.2947	2.4686	2.8885
	November	2.0331	2.3789	2.5592	2.9946
	December	1.9249	2.2523	2.423	2.8352
Annual average		**1.9021**	**2.2257**	**2.3944**	**2.8017**

The specific power density in the wind at the estimated height of 10m, 30m, 50m, and 150m was estimated using the formula 2 and the results are presented in Table 3.3. Our findings still confirming that Kanombe station is dominating other station with high average wind speed and high average power density because the power density is proportional to wind speed.

$$P = \frac{1}{2}\rho V^3 \qquad (2)$$

With P be the power density, ρ be the air density, and V the wind speed at a given height.

Table 3.3 Wind Characteristics of the Selected Locations

Locations	Wind speed (m/s)				Average power density (w/m^2)			
	10 m	30 m	50 m	150 m	10 m	30 m	50 m	150 m
Nyagatare	**1.0960**	**1.2824**	**1.3796**	**1.6143**	**0.8064**	**1.2917**	**1.6083**	**2.5767**

Ruhengeri	**1.6378**	**1.9164**	**2.0616**	**2.4124**	**2.6908**	**4.3109**	**5.3668**	**8.5991**
Kanombe	**3.6054**	**4.2188**	**4.5385**	**5.3105**	**28.7056**	**45.9910**	**57.2589**	**91.7302**
Byumba	**1.9463**	**2.2774**	**2.4500**	**2.8668**	**4.5158**	**7.2348**	**9.0075**	**14.4311**
Butare	**1.9021**	**2.2257**	**2.3944**	**2.8017**	**4.2151**	**6.7531**	**8.4081**	**13.4701**

The power density of 91.7m W/m^2 at Konombe at 150m height can be harnessed with a specific wind turbine. From the Table 3.3 above the power density observed for Nyagatare, Ruhengeri, Byumba, and Butare are very low.

3.4 Energy and Economic Development

Apart from living improvement due to electricity access for the connected customer(Households), it also contributes to the country's Gross Domestic Product growth through the revenue collected from electricity consumption. The electricity consumer in Rwanda is categorized as follows: Households, public service, industries, diplomats, non-industries, WASAC and public light. The households lead in revenue contribution followed by industries with 48% and 23% respectively in 2015/2016 in Rwanda (EDCL, 2017).

From Figure 3.1, It shows that, as The GDP increase, the electricity contribution also increases. This indicates how important electricity is needed to boost both country's economic and sustain her development. Due to the fact that electricity revenue affects the GDP growth, this can reflect the government, and see the energy sector as the important sector of GDP growth too. They can increase the budget and the effort provided for this sector in order to maximize its usefulness. The set target to increase electricity access to 70% by 2018 will contribute both to livelihood improvement and growth of electricity share in GDP. This Figure 3.1, clearly reveals the importance of electricity service in GDP growth. As the economy increase and the number of consumer increase, the revenue goes up too. Shifting from 8 billion Rwandan Francs in 2006-07 to 28 billion Rwandan Francs in 2015-16 is a good indicator of how electricity services are contributing much in country transformation. The government needs to ensure security in electricity generation and

service delivery to all the Rwandese so that effective contribution of the sector can keep increasing. Certainly, electricity share in GDP will keep increasing as the number of electricity access increase. If this 70% electricity access achieved, the share of electricity will increase to 65.3 billion Rwandan Francs which is significantly good share in GDP.

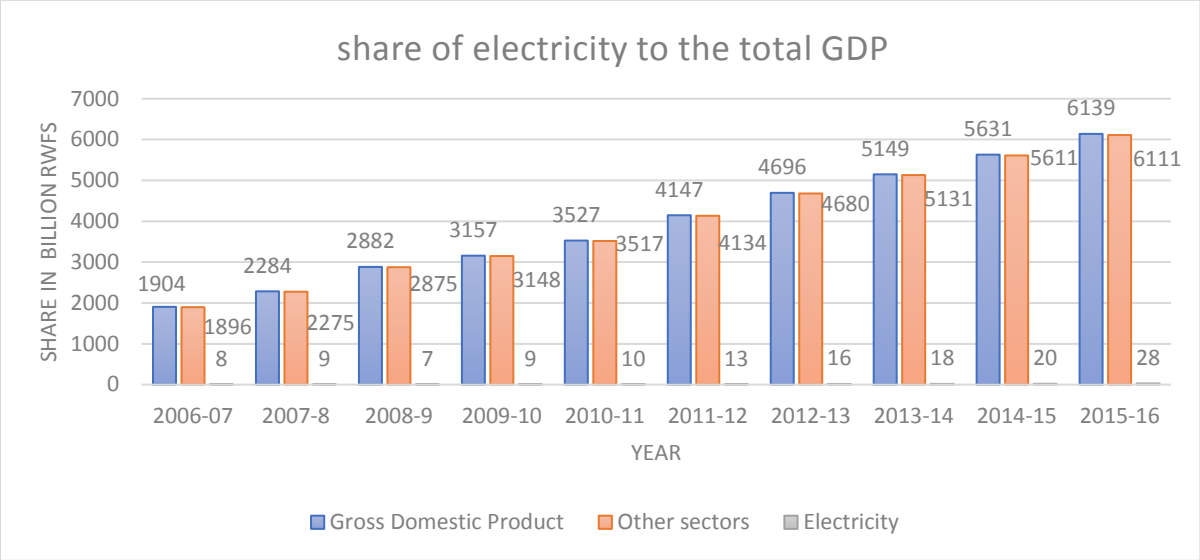

Figure 3.1: Share of Electricity to the Total GDP 2006-07 to 2015-16 (NISR, National Account, 2017)

Based on this economic growth chart above grounded on GDP increase, Electricity share is significantly good. Alongside with the country energy plan and looking at the investment made to increase the energy generation and electricity distribution to increase electricity access, we can figure out that there is energy market potential within the country.

In this period of rushing toward the country targets of 70% electricity access and expanding generation to 563 MW, renewables have an important role to play in them. Especially solar technology has a potential and high market in electrification process for remote areas than other renewable energy sources. Due to the fact that government is favoring the off-grid solutions especially solar and mini grid to reduce expenses in projects and energy loss, the renewable mini and off-grid energy project their market potential are undoubtedly approved. Renewable energy sources such as hydro, solar and wind where they are applicable like in these locations we analyzed for solar and wind this market is viable. In

reality, renewables can support economic development growth in a manner that is sustainable.

Table 3.4 GDP, Population, and Energy Generation Growth

(a)

Gross Domestic Product			
Year	Amount (billion Rwfs)	Increment (billion Rwfs)	%
2007	1904		
2008	2284	380	19.9
2009	2882	598	26.1
2010	3157	275	9.5
2011	3527	370	11.7
2012	4147	620	17.57
2013	4696	549	13.2
2014	5149	453	9.6
2015	5631	482	9.36
2016	6139	508	9.02
Average			**13.99**

(b)

Energy generation			
Year	Generation capacity (MW)	Increment (MW)	%
2009	85.2		
2010	95	9.8	11.5
2011	100.6	5.6	5.9
2012	111.9	11.3	11.23
2013	130.2	18.3	16.35
2014	163.2	33	25.3
2015	189.6	26.4	16.17
2016	194.3	4.7	2.48
2017	208.36	14.06	7.7
Average			**12.07**

(c)

Population			
Year	population	Increment	%
1978	4831527		
1991	7157551	2326024	48.1
2002	8128553	971002	13.56
2012	10515973	2387420	29.37
2015	11274221	758248	7.2
Average			**2.6**

The natural population growth rate was 3.7 percent between 1978 and 1991, while between 2002 and 2012 it was 2.69 percent. The overall growth rate was 2.6 percent between 1978 and 2015 [see Table 3.4 (c)] (NISR , 2016). The growth rate is not stable as we observe the different change in the increment percentage and the control in this will help to ensure its impact on the electricity supply and other sectors.

The increase in GDP [Table 3.4 (a)] occurs due to more improvements and modernization made in the major contributor such as Agriculture, Industry, Services, and Adjustments. Mechanization of agriculture requires energy from land preparation up to yield harvesting phase. The government is supporting the farmers anyhow to improve the production in both quality and quantity to satisfy the local market demand and the rest of the regional market. In the industrial sector, too many industries are coming in, and the existing are smoothing and expanding their activities, this is most often affect the energy sector. Improvement in services and new services introduced most of them require energy, this also is related to the energy side. That is why it is highly recommended for the government to ensure the change occurs in these activities and the relates the energy demand to energy supply to sustain country's development.

The energy generation growth in Table 3.4 (b), it is like in another sector, the annual increment is not stable. More change occurred but the sector increases generation from 2009 with 85.2 MW to 208.36 MW in 2017.

The growth in both population and GDP affects energy sector because it is increasing the energy demand. The growth rate presented in the [Figure 3.2] shows that all the sectors are growing to some extent every year. However, the growth rate is not stable this implies the instability in demand growth. The is a high variation in growth rate. This variation makes difficult planning process to meet all the demand side. Still, they lack the control to maintain the growth rate in energy, population and economic sectors, which indicate the

gap in the government's policies. The failure to stabilize the growth rate, undoubtedly, it is a barrier to satisfy and meet the planned target and probability for errors increased. The energy growth rate of 12.07% is not sufficient to meet the planned target of achieving 563 MW by 2018 from 208.36 MW in 2017. With this rate, it will require the government around 10 years (2026) to meet this target. In order to avoid this, they need to increase the generation growth rate to approximately 40% from now if there want to hit this in 2020. More need to be done in Rwanda energy sector in order to sustain the economic development.

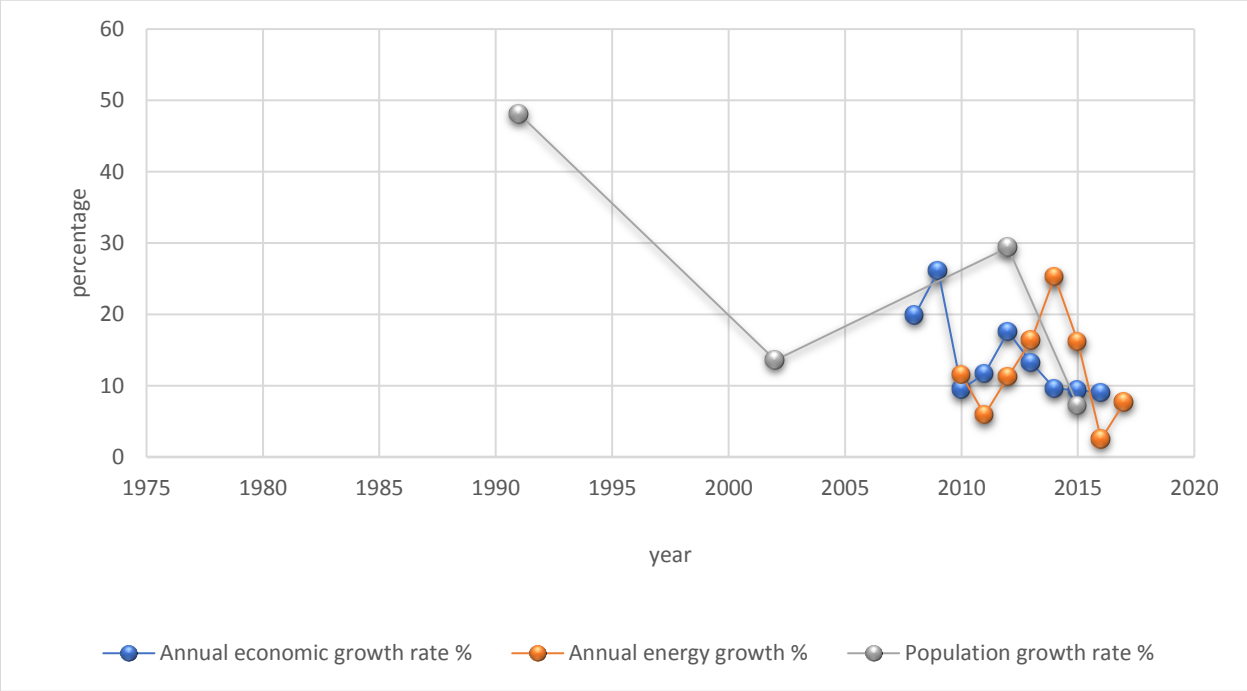

Figure 3.2: GDP, Energy Generation, and Population Growth Rate

What we observe above [Figure 3.2], we can guess that the policy in population is to reduce its growth rate, as the line is going down. In the GDP growth rate, the variation is not high since 2014 up to 2016. The GDP growth rate is somehow uniform, it is turning around 9%, But still affecting generation as the line is above generation line. Annual energy growth rate is growing but it is under economic line. This interconnects high demand to the current

insufficient energy supply. From 2016, it is seen that the generation is increasing and reach 7.7% in 2017, however, with this growth rate, it can be hard to meet the demand and sustain the development. It will be much better if the generation line moves above all the growth lines of these interconnected sectors.

3.5 Policy Implications

We are bearing in mind that energy policy it guides and facilitates implementation of the opted action to achieve the energy security, equity and environment sustainable in the development of the country. Based on that, we blame the current energy policy to be biased by no diversifying in total country energy generation.

It is not bad that energy policy can promote the use of hydro in electricity production, but for sustainability in energy production, it should consider other possible alternatives to support and secure energy supply. In deploying renewables, other sources like solar and wind should also be given the required attention in the country's energy planning. The research indicates that the wind has potential at a high height above the ground. Throughout the five locations we investigated, Kanombe is the top region with high wind speed that can be used to generate electricity in Rwanda. Solar is relatively good in all studied regions. However, proper assessment of all possible available renewable resources and potential is key in prioritizing energy promotion and development. Additionally, this will accelerate and further boost the country's economy through investing in the most sustainable and economically viable renewable energy sources.

Cross-sectoral policies put in place aimed at improving stability for renewable energy projects, reducing their risks and ensuring economic growth throughout all economic sectors of the country are key to creating enabling a business environment for renewable energy investments and economic growth in Rwanda. The expected future growth of the renewable energy sector will also require institutional capacity building and strengthen

domestic private renewable energy sector. Coordination of policy programs across sectors and inclusion of domestic society might ultimately
enable to further enhance economic growth of Rwanda. Due to implementing effective policies, Rwanda will be also considered as a stable developing economy that can achieve sustainable development and poverty reduction targets through utilization of the country's available renewables which will facilitate access to international investments in the country.

3.6 Gap: Challenges and Barriers to Renewable Energy Deployment

1. Relying on unapproved energy policy by cabinet.

The current energy policy was not approved by the cabinet (Ministry of Infrastructure, 2015a).This reflects the idea of unreliability on the side of stakeholders and reduces country's confidence at international level. Being not approved, it means that it is not completed to the level that meets the cabinet standard. The policymakers need to build policy, in a way that can be approved by the cabinet. We highly recommend them in policy formulation to base on deep research and involve all stakeholders such that all concrete elements can be tackled. The benefit of having approved policy includes:

- To raise the country's confidence,

- It will help to hold state's attention to support energy projects.

- It will help to convince the stakeholders, as it will be easy for the country to shows the line in which the country follows toward her target.

- It will encourage the stakeholders to support energy projects in clear guided manner.

2. Lack of country's specific Renewable Energy Policy.

Currently, both renewable and non-renewable energies are governed by the same energy policy. Having that the country is promoting renewables, the Energy Policy and Renewable Energy Policy should be separated to provide enough attention and make indigenous resources deeply exploited.

This has more advantage because it will deeply expose the potential of the available renewable energy resources and possibility in their exploitation across the country.

3. Lack of enough qualified people in Rwanda Energy sector.

One of the major challenge affecting the development of energy sector is the insufficient number of experts in the energy sector. Still, the available experts in Rwanda energy sector are not enough to speed up development and bring more change in energy across the country. The government needs to invest more in capacity building to increase the number of people with adequate knowledge in all energy technologies to ensure security in local workforces.

Having more expert will facilitate the development and implementation of the energy project and bring more valuable change in the energy sector.

4. Lack of clarification in target setting.

In setting a target to be achieved, the Government needs also to define load map to achieve them. Some target needs more clarification in them. Ex: 70% electricity access by 2017/2018. It is not enough to say 48% will be on-grid and 22% off-grid. What needed to be added, is the limitation in grid connection areas and off-grid connections areas. The targeted areas need to be identified and the technologies planned to be used specified. This specification should base on the available energy resources in the planned areas and the budget available. If the government does not have clear goals in plan and they are not aligned with her values and capacity it will result in target failure. This is what they are experiencing nowadays for some targets.

This will easy the implementation process as the load map will be clarified. This will help also the Government to achieve and optimize the investor and donor contribution.

5. Lack of detailed investment's information book.

Knowing that the government is attracting the investors in all means by providing some facilities and create a good environment to do business in Rwanda, there are still missing some important things. A detailed investment information book needs to be provided for all people who want to do business in the energy sector. Providing a full detailed investment information about energy will add more value to the support provided by the government and attracts more stakeholders. The document we suggest needs to provide all the basic business information related to energy in Rwanda. It will need to emphasis on energy opportunities, potential areas, estimated market, estimated cost for project implementation in the targeted village for both On-grid and off-grid projects. This book will provide Map presenting the information on the planned areas to be connected to the grid and off-grid.

Back on the current situation, when the investors come, they need to go first to identify themselves the areas they want to implement their projects, then after they come to REG/EDCL to check in GIS if the identified/ interested areas are not in areas planned for grid connection. And in this case, two things are possible, either to find the region in unplanned areas or to find it in planned areas. If they find it in planned areas, the investor needs to go back to assess another area which is not planned, about 1.5 Km away from planned areas. This is a discouraging double work and loss for the investor's money and time. This information needs to be provided before in this type of book. It should be built based on research conducted and collaboration with all involved institutions.

The government needs to allocate budget in the study as it is not an easy work to produce this book gathering all energy information within the country. In return, this will highly encourage the investors and scale up the use of renewables as well as accelerate the

electrification program. This mapping production will easy the discussion process between the investors and government as it will contain all needed information. What government will do, it is only to hand out the book to all those who show interest in investing in the energy sector, and also, they will need to update it regularly to remove the site which covered or booked. This will also help to avoid the conflict between the partners (investor and government). The government will recommend the further study, for the accuracy and exact benefit for the investors.

6. Lack of commitment to invest in new technology.

Most of the investment still go to the mature technology like hydro. Due to a low understanding about technology like geothermal, solar and wind their deployment within the country are little or do not exist. The commitment and investment related to its exploitation and development still low regardless its technical reliability and environmentally friendly compared to other options. The government should be committed to investing in new technology and being able to allocate budget in research and development of these technologies. Because they hold potential to support energy sector and sustain development.

This will strengthen the energy sector and boost energy generation relying on sustainable and reliable energy resources.

7. Lack of updated data.

In most cases, the sector relies on the country census and surveys(EICV) to get country's information related to their need. This survey occurs after periods of 5 years and because of having many objects to cover, the concentration on energy sector can be limited and delay. Lack of updated data highly affects the planning due to relying on old data. (Ex: currently there is no updated info on off-grid electricity users' due to the fact that there mostly dominated by private sector and it is not in their responsibility to report to anyone) the available data reported by Statistics was after 2012 Census and EICV4(2013/2014).

From 2012 up to now things have changed and improved. The agencies/ institution in charge can conduct their own energy survey to enrich their database. It is also possible in the agreement with the private sector to include the clause of providing a report regular on their customer growth just to have the information.

It is essential to update information, due to the fact that it assists in planning and give the real image of the current status. It will help also to show where the energy projects need to be directed and where much effort needs to be directed.

8. Lack of government commitment in grants/ funds application.

In what planned to increase energy generation all the projects planned its implementation rely on funds and grants. We can ask ourselves, what is the government contribution in this? The government needs to show its part. If they plan to increase they should plan also the budget to contribute with the partner. They might not cover 50% of the implementation, but taking some % percentage will be better. It can be 10%, 20% depending on the country economic and allocated budget for the energy sector to show up day after day.

This will bring positive impact in convincing the donors, how the government is committed to the project. This will encourage the donors, as it will strengthen the partnership and collaboration between stakeholders. In case these funds are not available, the government share can keep contributing in energy generation toward the planned target.

9. Risk in tariff setting.

The government is highly looking in privatization as one of the engines to speed up the development. In one way, we agree and other not. In negative side, privatizing all shares in energy generation, we can blame it to be responsible for high electricity tariff. The government should know that the investors are business people what they are looking for is the profits. The tariff will not decrease unless the government adds more subsidy. The government needs to develop a strategy bringing them back and hold share in a generation for the benefit of its citizen. Recall that renewable technology is quite expensive, the

private investors cannot sell their products to the low price unless government step in. In order hand, privatization it is good, as it brings more private and increases competition where in return affect the tariff. However, the competition to be productive needs the development of strict rules and regulations. That's why the government need to be involved to some extent in all the activities and strategies chosen for the benefit of the citizen.

In doing this the government will be able to protect the interest of the people in controlling the tariff which meets the people's capacity.

10. Mismatching responsibility for the Agencies.

In regulation, the agency responsible need to be involved in what there are regulating. Talking about RURA in the energy sector, being an agency apart which is not involving in any step of the energy sector (Generation, Transmission, Distribution) this favor errors in fixing tariff or other regulation because they do not know exactly what people there regulating do in the sector. This can affect both side production and customer in any way. The agency in charge needs to be involved in what they are regulating, in order to know more about the accurate information required to smooth their activities.

The benefit of this will come out, in doing the right things which are not biased for any side. The regulation will be based on the exact information, and in return, this will help in avoiding benefit conflict on the side of government, customer and investor/ producer.

11. Lack of project proposal developer team for fund requesting.

Lacking the team with the responsibility of developing energy projects to the extent that can meet the grant application requirements, it delays development of the sector. This highly affect the winning grant, due to the fact that, when the call for grant is announced, the government rush to fill the application form in a short period of time, where to meet the requirements is not an easy process as most of grant application requires facts based on the details and documents which cannot be found in short period including (Map indicating

the location of the project/program, Financial Model, Pre-feasibility Study, Feasibility Study, Environmental and Social Impact Assessment, Evaluation Report). The government should support the establishment of this team, and it should contain the expert in energy projects development with diversified knowledge in all fields and sectors.

The country will benefit from this team as it will be a strategy to:

- Easy the grant application process
- It will facilitate win process of the grants and funds
- I will encourage the stakeholders to support Rwandan energy projects due to the smoothness of the energy projects developed.

12. Lack of awareness on renewable energy.

Across the country, a large number of people do not know more about renewable energy. They do not know how good is to use renewable and how bad is to rely on non-renewable! No knowledge about the effect of climate change. It is not only the citizen even the leaders who can help to encourage people still unequipped. Talking about energy most of them hear electricity! This highly affects the development of the renewables deployment within the country. The people need to know and understand the reason why they are called to join renewable energies and energy efficiency. Basic information should be spread about the current form of energy used and climate change effects. Raising awareness among the citizen is a way to promote the use of renewables. Starting mobilizes the leaders and in return, they will transmit information and help to increase the number of people joining renewables. The government should develop a way/strategy of disseminating information for a large possible number of the citizen. This can be done through media, meeting, and so on.

As result, once awareness increased, it will be easy to call the people to join renewable technologies available and use them efficiently. Because of basing on tangible fact, this will reduce government task of taking alone the commitment to fight against the use of non-renewable and climate change.

13. Low investment in energy sector and related research.

With no research, it is hard to develop and bring innovation in the energy sector. Worldwide, the technology is improving day to day in all sectors for better use and management of the resources. The government should favor the establishment of research institution on the energy sector and all relevant subjects, to promote innovativeness in the sectors. Research is the engine of sector improvement and sustainability.

By investing more in research and development, it will help to boost energy sector to the standards and well adaptation of new technology, which will help to improve in all steps of energy production and utilization.

Chapter 4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Like many countries of Africa, renewable energy presents numerous opportunities in Rwanda energy sector. Renewable energy sources available in Rwanda range from Biomass, Hydro, Solar, Wind, and Geothermal where they have different potential. The Biomass dominates Rwanda's total energy supply with 85%, the same as in many African countries. Despite the fact that Renewables have different potential in Rwanda, their deployment in energy generation still low. Her electricity generation still highly rely on hydropower since 1957. In fact, Hydropower presented 60% of total installed capacity [Figure 2.3], solar 13%, wind 0%, the rest 27% in 2015. Right now, energy generation is not enough to meet the country demand.

Rwanda is among the first fast growing economy in Africa through the improvement made in the major contributor to GDP; Agriculture, Industry, Services, and Adjustments. In one way or another, these sectors highly affect Rwanda energy sector. Both growing in population and the change occurs in these main components of GDP are the major responsible for the instability observed in Rwanda energy sector.

Currently, to sustain country's economy and control the population growth in this period of high progress while meeting the total energy demand, it is never as simple as it seems and the government is running into many obstacles. It requires more effort and government attention to ensure energy security and equity across the country because the government will have many tough sacrifices to make and strong decisions to take along the way.

As the energy is the key driver of the development, Rwanda set a high target in the energy sector to be achieved by 2018 and other 2020. Often the problem is not so much about the high target, but more how focused and committed the government is towards her target as she moves on. Too many gaps were observed in energy sector concerning development and deployment of renewables within the country. These include; weak institution, lack of awareness on renewable energy, insufficiently qualified people in the energy sector, low

investment in new technologies, non-existence of appropriate policy for renewables. There are no magic pills, to achieve the set target, the government has to show up day after day.

In this work, what has been found so far actually shows Rwanda energy situation, economic progress, and population growth as the major interlinked sectors defining country's stability.

All these sectors were considered during development of energy policy and EDPRS I & II toward vision 2020, with precise predictions in their growth. However, the current situation reveals different image to what was planned. This also implies the failure of the policies formulation to set a realistic target. The government lacks the strategies and tangible measures to control the imbalance occurred in the growth rate of the major economic drivers. Some goals were not clear and they are not aligned with a country capacity which results in goals failure (Ex: Biomass reduction from 85% to 50% by 2018, Increasing electricity access from 30% to 70% by 2018, Increasing generation from 208.36MW to 563MW by 2018).

The results of this work reveal that the diversification in electricity generation is not promoted. The policy in place highly still promote the use of hydropower regardless its limited potential within the country. Renewable energy sources like solar and wind which emphasized in this work proven to have the potential to some extent in considered locations. They can be used to solve the problem occurs in the energy sector and sustain economic development in a manner that is reliable. However, their potential didn't recognize among the possible indigenous resources especially wind energy source during policy formulation. This was a blame on the policy developers who did not base on deep research about the possible alternatives sources available in the country.

More to the point, the energy policy available highly still promotes hydropower. Looking at the current projects and plan it is still expected more from local and regional hydro energy resource projects to boost energy sector. It provides a clear pathway in hydro exploitations than other renewables.

Before making a short and long-term plan, it is best to know yourself very well, what is your potential. Solar and the wind have potential to extent that can contribute considerably to energy generation and other applications within the Country. In the five locations we studied, the solar potential is relatively good. In the whole year, the peak hours range from 11h to 15h. It is not in all the locations have the potential for the wind but at Kanombe's wind can be an option to sustain the energy sector. its average wind speed reaches 5.3m/s at 150m which is good for energy generation.

The meteorological data analyzed in this work, prove different potential available for solar and the wind in five locations. This highly confirms that diversification in energy generation is a right option to solve energy issues across the country.

Until now, Rwanda is speeding up her activities by seeking out ways to achieve her vision of transforming Rwanda into a middle-income country by 2020. The policies in place aimed at improving sustainability in the key business players, reducing their risk and ensuring economic growth and poverty reduction. Both Rwandese and all economic sectors of the country are key to creating enabling a business environment for renewable energy investments and economic growth within the country. By providing more facilities and easy condition to do business, the Rwandan government is opening the door for all the investors. Enforcement and good coordination of policy programs across sectors and high involvement of local society undoubtedly are required to further enhance economic growth of Rwanda. The energy policy needs to be formulated in a way that it tackles all the possible alternative available based on the potential of the indigenous resources.

In retrospect, we believe that this will accelerate and further boost the country's economy through investing in the most sustainable and economically viable renewable energy sector while attracting more international investments in the country.

Due to amalgamation constraints including time limit, this means the need for further study to ensure smooth and completeness of this study. The further study can consider the following:

1. Analysis of data with other tools (Software like MatLab) and consideration of data of many years
2. Projects design to harness identified power available in identified locations
3. Identification of others potential locations for renewables (Wind and Solar)

4.2 Policy Recommendations

- ✓ Energy Policy developers should work closely with researchers, country's statisticians for better outcomes. This will help to relate the growth rate in all possible sector affecting energy sector. In addition to this, it will help to make a better realistic plan and projection toward the country's vision. Some of the gap observed was due to lack of information based on deep research, the developers were too general and want to use the easily available information. For instance, talking that the wind does not have any potential it is not true, few available information's on wind limited at height of 10 m above the ground. Even this it is not the research conducted for the whole country, the available information is for some sites. We think that the reason why they highly focus on hydro power, first, it is a mature resource and its information is easily available in the country. Back on Solar potential, the available information proved its potential to a good level, however, the research is needed to witness more about what it can be used for in each specific location. It is not only solar and the wind needs further research, even geothermal and other renewables. The high recommendation in collaboration of all involved institutions and Agencies it is to ensure that all stakeholders were consulted in order to avoid miss planning and conflicts. Talking about conflict, there is a high probability that conflict will occur between the energy sector and Rwanda Environment Management Authority (REMA). Currently, there is not

available plan about energy waste disposal (especially solar panel and batteries used in PV system) within the country. REMA, Ministry of Infrastructure, REG and all those involved stakeholders should start now think and plan about this issue in order to secure better future environment.

- ✓ Before energy policy being published, it should be approved by the cabinet for better enforcement in implementation. Having approved policy will raise the country's confidence, and It will also help to hold state's attention to support energy projects. It will help to attract and encourage more stakeholders to support energy projects. In Rwanda, most projects require government participation for their implementation, they are highly affected by government prioritization which based on population crucial needs. This delay implementation of many projects and results also in target achievement delay too. To avoid this in the development of energy projects, both energy policy and renewable energy policy need to be approved. Currently what approved by the cabinet, somehow it becomes more like a law. Once they are approved, the development of energy sector will be among the top priorities within the county.

- ✓ To ensure better use and promotion of renewables in the economic development of Rwanda, it is highly likely that Energy Policy and Renewable Energy Policy would be developed separately. In so doing this, it will contribute to make indigenous resources deeply exploited and fit their need precisely. Currently, the available policy draft guides the exploitation and use of all energy sources available in the country together. This result in a lack of attention put for specific sources and favor the use of easily available resources. By developing renewable energy policy apart, it will help to increase required attention in renewables deployment and promote deep research on the available renewable energy sources such Solar, Wind, Geothermal and bioenergy within the country. The quickest way for the country to

adopt a new technology is to have a clear understanding of it first. The good way to deploy renewables effectively to sustain Rwanda's economic development growth is to build a specific renewable energy policy by investigating them deeply to know the availability of every renewable energy source within Rwanda. Then as they build on that investigation, the government will understand the possibility of renewables deployment in each corner of Rwanda.

- ✓ As the peak hours for solar is from 11h to 15h, there are two possible options which can be recommended to harvest this inexhaustible free energy source. This energy exploitation can be harvested with the need of storage(battery) or it can be harvested with no storage for direct use or for grid connection. These options are all possible for solar in Rwanda. The wind also has potential as we go high above the ground. The government needs to carry out further research on the feasibility of the approved potential in these locations. The possibility is not only in these five locations but also in other areas, the research should be extended across the country.

- ✓ Diversification in energy investment is highly recommended for the government in order to easy and speed up the target achievement. Currently, it is still hard to meet up the set target of 563 MW and achieving 70% of electricity access by 2018. However, by looking all possible option and share the effort put in energy generation, it can be a better option to make a change in the energy sector. Talking about the possible energy resources, within the country there is a high potential in biogas. Based on the current program of One Cow per Poor family (Girinka Program) introduced by President to help Rwandese improve their livelihood, the program could be systematically extended to other big institutions such as schools, hospitals, and prisons among others. At households' level, for those with at least two cows could be encouraged and assisted in setting up biogas digesters. Such programs can significantly contribute to country's renewables deployment through increasing biogas generation.

- ✓ In policy formulation and strategic plan, they should provide full and clear details on the way to achieve desired goals. It should specify clearly implementation process, Timeline of each action, the task of each stakeholder, specific measures and alternatives when the external factors disrupt, and the way to follow up. Currently, some energy projects delay and other fails because of lacking a clear and specific attention in their planning (Ex: Geothermal projects). The government needs to form a specific strong team of the experts to analyze and inspect the energy projects from the beginning date up to commissioning date. The team will ensure that all required and necessary details for better implementation are provided in both government and private projects. The team will ensure the implementation progress.

- ✓ We highly appreciate the country's collaboration with the international development partners (World Bank, African Development Bank (AfDB), Japanese International Cooperation Agency (JICA), Arab Bank for Economic Development in Africa, Cooperation Technique Belge and the Netherlands and France) in the development of energy sector. Even if this works, the government should not often rely on the funds and grants during their planning to increase the generation and secure the energy sector. Self-reliance provides more security than other option. The energy policy should provide the specific role of the government on its own, depending on its ability instead of waiting for the funds to run its projects. Having said this, we want to emphasize that, the energy policy needs to give clear implementation process specifying the amount of energy the government is able to add on its own periodically and what they will need from the external collaboration. In so doing this it will help to avoid failure and delay in goals achieve.

- ✓ The energy policy should favor the establishment of research institution on the energy sector and all relevant subjects, to promote innovativeness in the sectors. This also recalls the government's attention to reinforce and invest more in capacity building in order to increase the number of people with adequate knowledge that we need to facilitate the development and implementation of the energy projects and bring more valuable change in the energy sector. More to the point, there are the amazingly two suggestions we can make. First, because of her low capability to teach and use energy especially renewables within Rwanda, it is good to promote partnership with Universities and research institutions from developed countries where renewables deployment far exceeds other sources. Therefore, they can exchange knowledge by sending students abroad to study or the Experts/Lecturer may come to train and teach about energy within the country. We believe that through this way Rwanda can increase a bit the number of experts in the energy sector. Second, in cooperation with the Ministry in charge of Energy(MININFRA), the Ministry of Education should try to review the curriculum at a secondary and tertiary level in order to introduce energy courses which would include a strong foundation in renewable energy sources deployment. Undoubtedly this can bring positive results to solve the problem in a sustainable manner.

- ✓ To ensure better management of the energy resources and good use of available energy, the energy efficiency, and energy conservation have to be tackled and be emphasized deeply. All the stakeholder should be informed about this. Yet before the country blames herself and declares insufficiency in energy supply, she needs to ensure good and efficient use of the available energy. While disseminating the information about the importance of renewables, the stakeholders should be taught about energy efficiency and energy conservation. Rwanda is a small country in size and most of the people live in the artificial village, and the communication process can be easy to reach them. The energy information can be spread via the meetings,

Radio and TV publicity and so on. Far more is gained when the utility identifies the way to control the demand without increasing power supply, rather than increases generation.

- ✓ According to investment costs, operation and maintenance costs for the on-grid system, the use of the off-grid system is far more effective than grid connections in electrification, especially in remote areas. This back to the potential of the indigenous resources, where it is applicable solar and the wind can be a better option to go. The policy should consider this in order to promote the deployment of these renewables. Additionally, electricity transmission's losses due to long transportation will be significantly reduced by enhancement of off-grid solutions to power remote areas.

- ✓ The current research often praises solar for its potential, despite the reality that they are several problems associated with its use in Rwanda. Due to the problem of land in Rwanda, Solar roofing system should be highly promoted to avoid the conflict with another sector, especially agriculture. In addition to this, the issue of energy waste disposal should be tackled. The energy policy needs to be developed in the way that all points recognized. It is through the collaboration and involving all stakeholder this can be handled.

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APPENDICES

Appendix 1: Rwanda Electricity tariff

ANNOUNCEMENT.

The Management of Energy Utility Corporation Limited (EUCL) wishes to inform its esteemed customers that the new electricity tariff as approved by the RURA Board of Directors; in its decision N° 05/BD/ER-LER/RURA/2016, from the session of 13th/12/2016 will be effective starting 1st January 2017as follows;

1. **RESIDENTIAL CUSTOMERS:**

Consumption (kWh) block/month	FRW/kWh (VAT exclusive)
[0-15]	89
]15 – 50]	182
>50	189

2. **NON- RESIDENTIAL CUSTOMERS**

Consumption (kWh) block/month	FRW/kWh (VAT exclusive)
[0 -100]	189
>100	192

3. **INDUSTRIAL CUSTOMERS**

Designation	Basis of charge	Tariff (VAT exclusive)
Small industries including Water treatments plants, Water pumping stations, and Telecom towers		
Flat rate	Rwf/kWh	126

MEDIUM INDUSTRIES: (0.4 Kv<V≤15kV)		
Energy Charge	Rwf/kWh	90
Max. Demand Charge (17H00-23H00) **Peak**	Rwf/KVA/month	10,469.55
Max. Demand Charge - (08H01'-16H59') **Shoulder**	Rwf/KVA/month	5,588.41
Max. Demand Charge-(23H01' – 08H) **Off-Peak**	Rwf/KVA/month	1,891.54
Customer Service Charge	Frw/Customer/Month	3,125

LARGE INDUSTRIES: (>15 Kv<V ≤ 33 kV)		
Energy Charge	Rwf/kWh	83

Max. Demand Charge (17H00-23H00) **Peak**	Rwf/KVA/month	7,184.44
Max. Demand Charge - (08H01'- 16H59') **Shoulder**	Rwf/KVA/month	4,004.16
Max. Demand Charge- (23H01' – 08H) **Off-Peak**	Rwf/KVA/month	1,085.86
Customer Service Charge	Rwf/KVA/month	3,125

For further information please contact our nearest Branch, Commercial Department at Headquarter, toll free line **3535**, website, twitter account and Face book page.
The EUCL management appreciates your full cooperation and collaboration in implementing this new tariff