Inventory Analysis Of Power Plants In Rwanda And Estimated Generation Capacities

Eustache Hakizimana, Diego Sandoval, U. G. Wali, Kayibanda Venant

Abstract: This study presents the findings of an inventory assessment of all power stations in Rwanda. The main objective is to investigate the operational and planned production of power plants and their surrounding environment, and to support the development of plant performance, and to recognize the characteristics of these structures from the energy technology perspective. Five different (operational / proposed) power generation systems such as hydropower, biomass, methane gas (phase I of Kivuwatts), thermal power plants (diesel and heavy fuel generators), and solar power plants were examined in this study. The electricity generated from each power plant was taken from the systems using a combined process analysis method and analysis of the input / output. First, average power generation systems representing the current status had been introduced in Rwanda. Second, we examined the effects of current clean energy technologies as well as potential ones. The inventory assessment of the power plant was carried out on the current and planned interconnectors, the results of this study show that the most dominant power plants, including water, sunlight, methane at the bottom of Lake Kivu and peat reserves in the southern province, are mainly serviced by diesel power plants during peaks and seasonal input from major hydroelectric power stations on the grid. The difference between power generation costs and electricity prices is high, and the availability is reduced. As a result of this analysis, in order to help decision-makers, all the influential performances of electricity generation based on existing resources and their shares.

Keywords: Renewable energy technology, Non-Renewable energy technology and inventory analysis

1. Introduction

Rwanda is endowed with a myriad of natural resources, the most dominant of which includes water, sunshine, and methane at the bottom of Lake Kivu and peat reserves in the southern part of Rwanda. It is therefore important that these resources are identified and utilized for electricity production in the most cost-efficient manner while meeting the demand and reserve margin needs. The electricity supply of Rwanda is composed of domestic generation and the imported electricity from neighbor countries and regional shared power plants. The source of energy used is from the following sources: hydropower plants, thermal power plants (diesel and heavy fuel generators), methane gas and solar energy [1]. The following research questions were formulated for the purpose of this study: Does successful inventory analysis ensures a continuous output of power plants in Rwanda? What are the States of Rwanda's planned and operating power plants? Has successful inventory analysis significantly impacted the output of power plants? One of the basic goals of inventory analysis of power plants and their operation is to maintain inventories at a sufficiently high level of output to be completed. Rwanda's energy sector can be characterized as a semi-bundled system and all functions of generation, bulk transmission and distribution are performed by the state owned utility Rwanda Energy Group (REG) through its subsidiaries Energy Development Corporation Limited (EDCL) and Energy Utility Corporation Limited (EUCL) [2]. The government has opened up the generation Subsector to independent Power Producers who can sell power to the utility.

- Eustache Hakizimana, Diego Sandoval, U. G. Wali, Kayibanda Venant
- 1, 2 African Center of excellence in Energy for Sustainable Development, University of Rwanda, Kigali, Rwanda
- 3 Department of Civil, Environmental and Geomatics Engineering, University of Rwanda, Kigali, Rwanda
- 4 Department of Mechanical and Energy Engineering, University of Rwanda, Kigali, Rwanda
- Correspondence: haki2012eustache@gmail.com

The Rwanda Utilities Regulatory Authority (RURA) regulates both the power and gas sectors. It handles licensing Independent Power Producers (IPP´s); Enforcing approved technical standards, independent electricity regulatory and setting, reviewing and approving electricity tariffs and Power Purchase Agreements (PPA´s). The Rwanda Development Board (RDB) facilitates private sector investments in energy. To date, 51% of Rwandan households have access to electricity, connected to the national grid (37%) or through off-grid systems (14%) [15]. The objective of this study is to quantify and aggregate the operational and planned power plants in Rwanda and provide suggestions for improving the output of power plants with the appropriate parameters. A method was used that was based on the geographical location approach. In this study renewable and non-renewable energy technologies were inventoried. Decisions on inventory analysis are focused on information quality and the efficiency of defining the key variables.

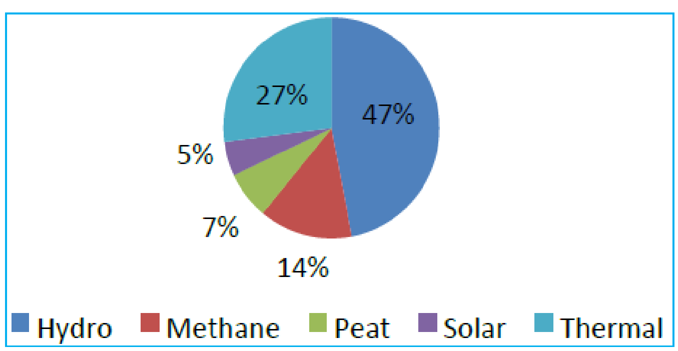

Figure 1: *The current Power Generation Mix in Rwanda*

2. Related Literature Review

The electricity supply of Rwanda is composed of domestic generation and imported electricity from neighbor countries and regional shared power plants. The source of energy used is from the following sources: hydropower plants, thermal power plants (Diesel and Heavy fuel generators), methane gas and solar energy as shown in figure 1.

Table 1: *Rwanda's main sources of energy for electricity generation [2]*

S/N	Power Plants	Characteristics	Status
1	Hydro power	It is the most widely used form of renewable resources for electricity generation in Rwanda and power plants are either publicly owned and operated, leased to private companies, or privately owned Independent Power Producers (IPP).	29 Operational
			28 Planned (22Hydro Stations<=5MW, 4 Hydro Stations>5MW and 2 Regional Projects)
2	Solar power	It is generally characterized by Savannah climate and its geographical location endows it with sufficient solar radiation intensity approximately equal to 5kWh/m^2/day and peak sun hours of approximately 5 hours per day	4 Operational
			2 planned
3	Peat power plants	Estimated reserves of 155 million tonnes of dry peat spread over 50,000 hectares	1 Operational
			1 planned
4	Gas-fired generation (Methane Gas)	Estimated reserves of 55 bcm* in Lake Kivu	1 Operational
			1 planned
5	Thermal power (Diesel and heavy fuel generators)	Currently, there are five Diesel power plants in Rwanda are generating 26.76% of the total electricity in Rwanda.	3 Operational
			2 planned
6	Geothermal	The potential of about 700 MW but roughly 490 MW is economically recoverable	Geothermal energy potential has in the past been explored , but has since been proven commercially unviable
7	Biomass	Wood –based and Biogas	Operational for cooking, not used for power generation

3. Current status of power plants in Rwanda

Hydropower plants, thermal power plants (Diesel), and solar-photovoltaic power plants were studied in three different types of power generation systems. The following parts provide a thorough analysis of the systems. To-the high level of reliance on diesel power, different generation expansion scenarios have been generated and modelled with a view to using various technologies to generate electricity on the Rwandan grid. The commissioning dates of key planned projects for the near term were also used to evaluate an optimal mix of generations for the country. In addition, the six small HPPs are scheduled for commissioning in the fiscal year 2019/2020. Both the committee and soon-to-be commissioned power plants were hard-wired into the least-cost software, i.e. with definite commercial operation dates (CODs) [2]. Rwanda has considerable energy development opportunities from hydro, methane gas, solar, peat deposits, and geothermal, wind, and biomass energy sources that have not been fully exploited for power generation. The systems studied as an inventory analysis of electric power generation are shown in Figure 2. Maintenance and operation were investigated at each stage and decommissioning was not performed in this study. Table 2 lists the current generation plants and their related characteristics within Rwanda [2].

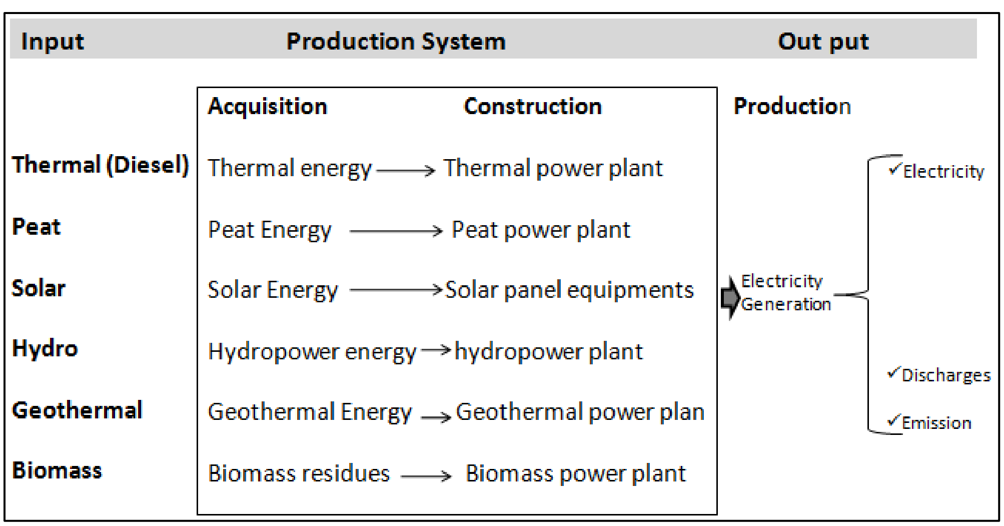

Figure 2: *Inventory analysis of electric power generation*

4. Research Methodology and Data Collection

Data collection efforts involve a combination of research, site-visits and direct contact with plant managers and experts, which generates large quantities of data. The research study employs two sources of data, the primary and second data. Primary data was collected from the Rwanda Energy Group (REG) in the sample area through a structure questionnaire and interview. The secondary data were obtained from both electronic and printed media. Monthly papers, journals, written technical reports, research works, unpublished business studies and textbooks are included in the printed media. The origins of electronic media include digital files, directories and an annual inventory report. Python/Jupyter notebooks and QGIS software were also used for data analysis and visualization. The inventory analysis is the crucial phase of the Life Cycle Assessment (LCA) that involves gathering the input and output data required to meet the study's objectives. A physical assessment of all Rwandan power plants was performed in accordance with ISO standards (ISO14040:2006 and ISO14044:2006).

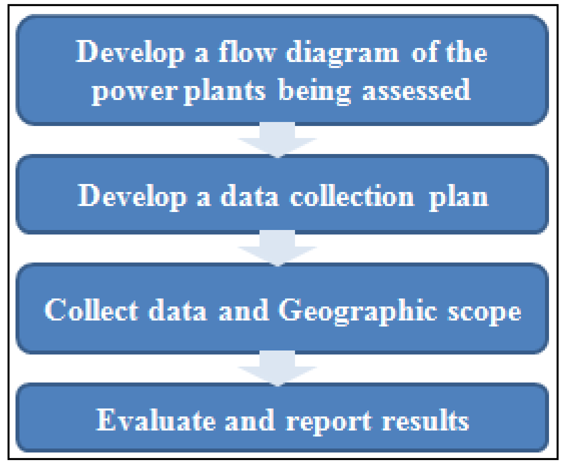

Figure 2: *framework for performing an inventory analysis and assessing the power plants in Rwanda*

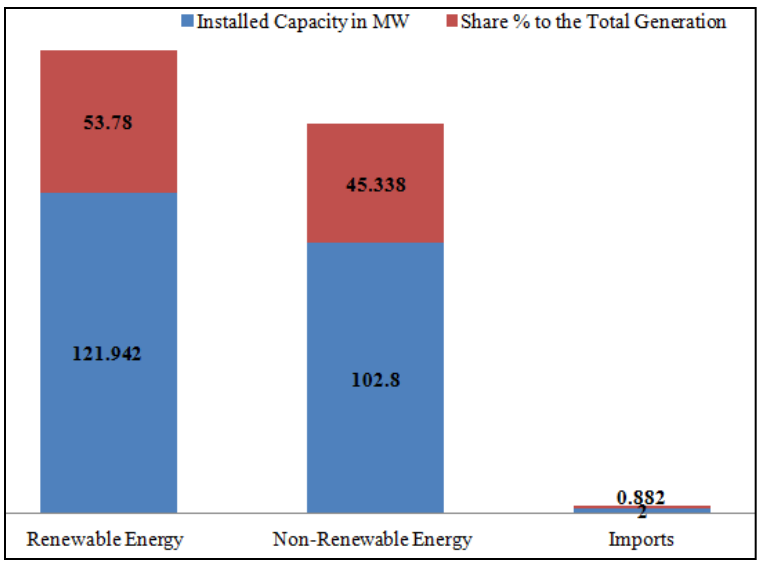

Figure 3: *Total installed capacity of each power generation technology*

Table 2: *Summary of existing power plants and respective generation capacities*

No	Plant Name	Installed Capacity (MW)	Capacity Factor (%)	Available Capacity (MW)	Owner	COD	Types	Geographical Info (Latitude, Longitude)
1	Ntaruka	11.25	23	2.5875	Government of Rwanda	1959	Hydro	-1.477357, 29.750290
2	Mukungwa I	12.00	50	6	Government of Rwanda	1982	Hydro	-1.536787, 29.683206
3	Nyabarongo I	28.00	48	13.44	Government of Rwanda	2014	Hydro	-1.979420, 30.044180
4	Gisenyi	1.20	65	0.78	Prime Energy	1957	Hydro	-1.710112, 29.265237
5	Gihira	1.80	70	1.26	RMT	1984	Hydro	-1.766800, 30.121900
6	Murunda	0.1	45	0.045	Repro	2010	Hydro	-1.911130, 29.372620
7	Rukarara I	9.5	40	3.8	Ngali Energy	2010	Hydro	-2.453851, 29.464368
8	Rugezi	2.6	50	1.3	RMT	2011	Hydro	-1.5074437 29.906345
9	Keya	2.2	50	1.1	Adre Hydro	2011	Hydro	-1.704879,

					&Energicotel			29.312893
10	Nyamyotsi I	0.1	60	0.06	Adre Hydro &Energicotel	2011	Hydro	-1.944880, 30.062380
11	Nyamyotsi II	0.1	60	0.06	Adre Hydro &Energicotel	2011	Hydro	-1.972970, 30.049520
12	Agatobwe	0.2	35	0.07	Carera-Ederer	2010	Hydro	-2.607112, 29.745227
13	Mutobo	0.2	45	0.09	Repro	2009	Hydro	-1.508594, 29.579923
14	Nkora	0.68	50	0.34	Adre Hydro &Energicotel	2011	Hydro	-1.849609, 29.299203
15	Cyimbili	0.3	50	0.15	Adre Hydro &Energicotel	2011	Hydro	-1.822400, 29.299900
16	Gaseke	0.582	90	0.5238	Novel Energy	2017	Hydro	-1.768992, 30.122833
17	Mazimeru	0.5	49	0.245	Carera-Ederer	2012	Hydro	-1.898150, 30.095056
18	Janja	0.2	80	0.16	RGE Energy UK ltd	2012	Hydro	-1.680860, 29.681360
19	Gasashi	0.2	40	0.08	Prime Energy	2013	Hydro	-1.806863, 29.292631
20	Nyabahanga I	0.2	55	0.11	Government of Rwanda	2012	Hydro	-2.077880, 29.416320
21	Nshili I	0.4	60	0.24	Government of Rwanda	2012	Hydro	-2.755641, 29.459623
22	Rwaza Muko	2.6	60	1.56	Rwaza HydroPower Ltd	2018	Hydro	-1.548300, 29.629450
23	Musarara	0.45	49	0.2205	Amahoro Energy	2013	Hydro	-2.345900, 29.505200
24	Mukungwa II	2.5	73	1.825	Prime Energy	2013	Hydro	-1.581741, 29.655042
25	Rukarara II	2.2	52.5	1.155	Prime Energy	2013	Hydro	-2.459405, 29.435803
26	Nyirabuhombohom bo	0.5	35	0.175	RGE Energy UK ltd	2013	Hydro	-1.944880, 30.062380
27	Giciye I	4	40	1.6	RMT	2013	Hydro	-1.695097, 29.572642
28	Giciye II	4	40	1.6	RMT	2016	Hydro	-1.972970, 30.049520
29	Ruzizi II	12.00	89	10.68	Government of Rwanda	1984	Hydro	-2.63344 28.90266
30	Jabana 1	7.8	95	7.41	Government of Rwanda	2004	Diesel	-1.890537 30.066253
31	Jabana 2	21	95	19.95	Government of Rwanda	2009	HFO-Diesel	-1.882258, 30.074238
32	So Energy	30	95	28.5	So Energy&SP	2017	Diesel	-1.502179, 29,644929
33	Gishoma	15	95	14.25	Government of Rwanda	2016	Peat	-2.617881 28.936126
34	Biomass (Rice Husk)	0.07	95	0.0665	Novel Energy	2016	Biomass	
35	Kivuwatt Phase I	26.4	100	26.4	Contour Global	2016	Methane (Gas Extractio n)	-1.944880, 30.062380
36	Jali	0.25	14	0.04	Mainz Stadwerke/ Local Agency	2007	Solar	-1.884761, 30.016139
37	GigaWatt	8.50	14	1.19	Gigawatt Global	2013	Solar	-1.944880; 30.062380
38	Nyamata Solar	0.03	35	0.01	NMEC Nyamata	2009	Solar	-2.285092; 30.23122
39	Nasho Solar PP	3.30	20	0.66	Government of Rwanda	2017	Solar	-1.884025; 30.016380
40	Ruzizi 1	3.50	100	3.50	Snel Sarl	1957	Imports	-2.557920; 29.114010
41	UETCL	2.00	100	2.00	UETCL	2016	Imports	-1.944880; 30.062380

5. Research Findings and Discussion

5.1 Visualizing the Data

Data visualizations in this study need to be easy to understand and to improve interaction with research results by allowing the reader to interact with the data. Geospatial data should be geographically accurate (called geo-referenced or geocoded) and its parameters should be used to improve the location of power plants on the Rwandan map. Data analysis was conducted using Python / Jupyter-Notebook and defined as a process consisting of several steps in which the raw data is transformed and processed in order to generate data for visualization and can make predictions thanks to a mathematical model based on the data collected. Then, the process of analyzing the data using analytical and statistical tools to find useful information, to inform conclusion and to help decision-making, the aim of geopandas is to make it easier to work with python geospatial data. It incorporates pandas and shapely skills, offering shapely geospatial operations in pandas and a high-level interface to multiple geometry. We stated the Coordinate Reference Systems (CRS) is important because in an arbitrary space, the geometric shapes in a geoseries or geodataframe object are simply a set of coordinates. A CRS tells Python how those coordinates apply to Earth's locations. EPSG stands for the European Petroleum Survey Group and EPSG: The widely used latitude / longitude coordinate system is 4326 (also known as the WGS84 World Geodetic System 1984). Figure 3 demonstrates the capacity built from each Rwandan generation technology and Figure 4 shows the geographic location of each power plant.

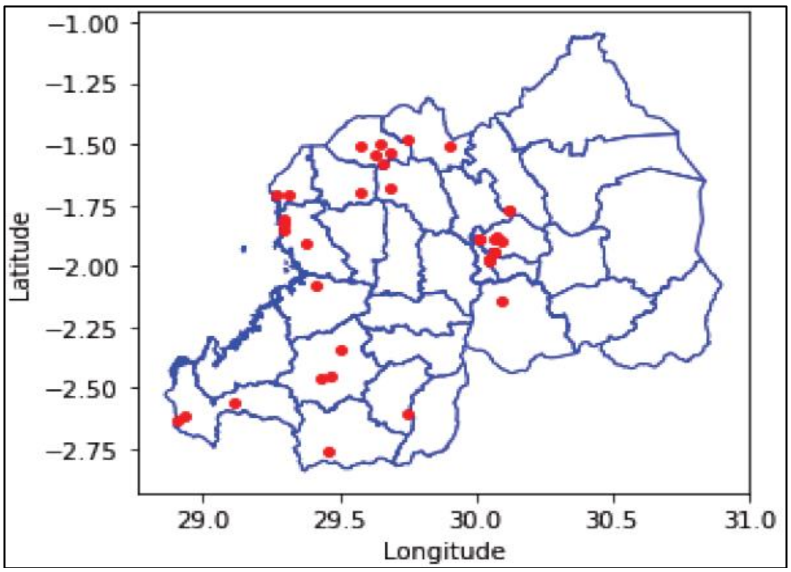

Figure 4: *Locations of each power generation technology in Rwanda*

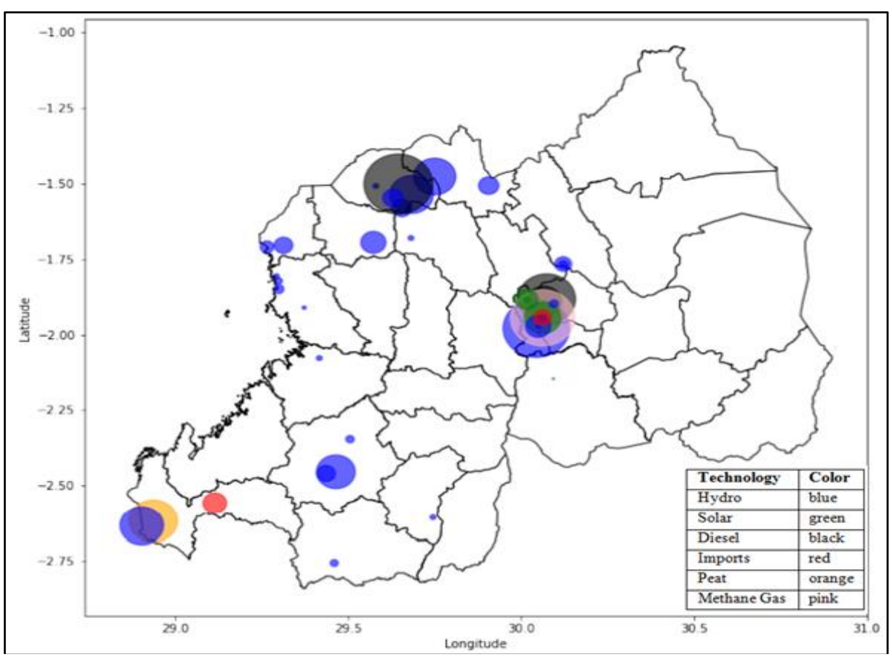

Figure 5: *The bubble sizes represent the installation capacity of each power plant*

5.2 Data Analysis

The data gathered for this study were derived from the process of literature review, historical data, geographical information and observation. These data were then transformed into qualitative information to facilitate analyzes and assessments. Costs for generation vary according to the technology used. It varies from 10 to 33USD cents. Researchers must first identify the fault by analyzing the plant failure, and figure out all possible causes. If the causes are found, agreement must be reached with the equipment or replacement parts to be used in the methods to use them and write them down. The power plant's productivity is enhanced by running the facility, according to the operation and maintenance procedures manuals. Once there is a fault occurrence, the time used should be condensed as much as possible. Preventive maintenance must be applied as per manuals. In any power plant, maintenance can not prevent the fault occurrence or happen. It does only minimize the risk and the time taken should be minimized in any way. The main challenges are just the availability of spares and network instability. Currently, the total installed capacity to generate electricity in Rwanda is 226.7MW from more than 40 power plants, mainly hydro. Only 1.62% of the available capacity is imported while the rest is domestically generated and the number of on-grid connection has grown 10 times over the last 10 years as shown in figure 6. Thirty-nine percent of generation technology is from hydrological energy, followed by methane gas (25 percent) and 19 percent thermal sources. As of October 2019, 53 per cent of Rwandan households had cumulative connectivity rates, including 38 percent linked to the national grid and 15 percent accessed via off-grid systems (mainly solar) as shown in figure 7 and figure 5 shows the geographical location and bubble sizes represent the installation capacity of each power plant.

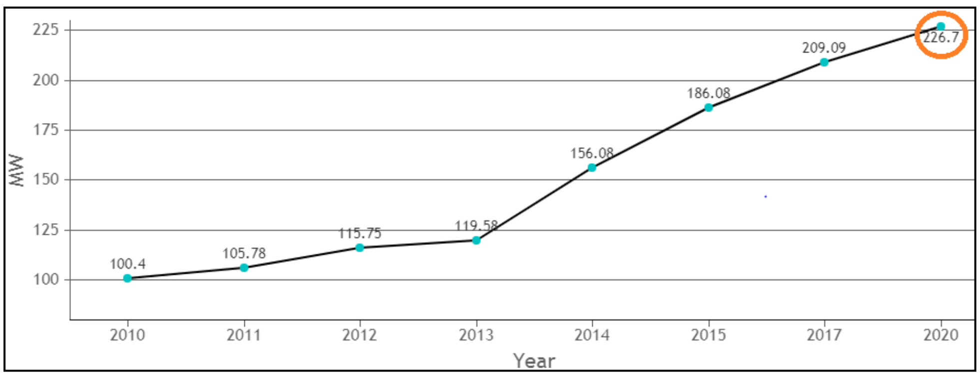

Figure 6: *Evolution of the installed generation capacity on the national grid*

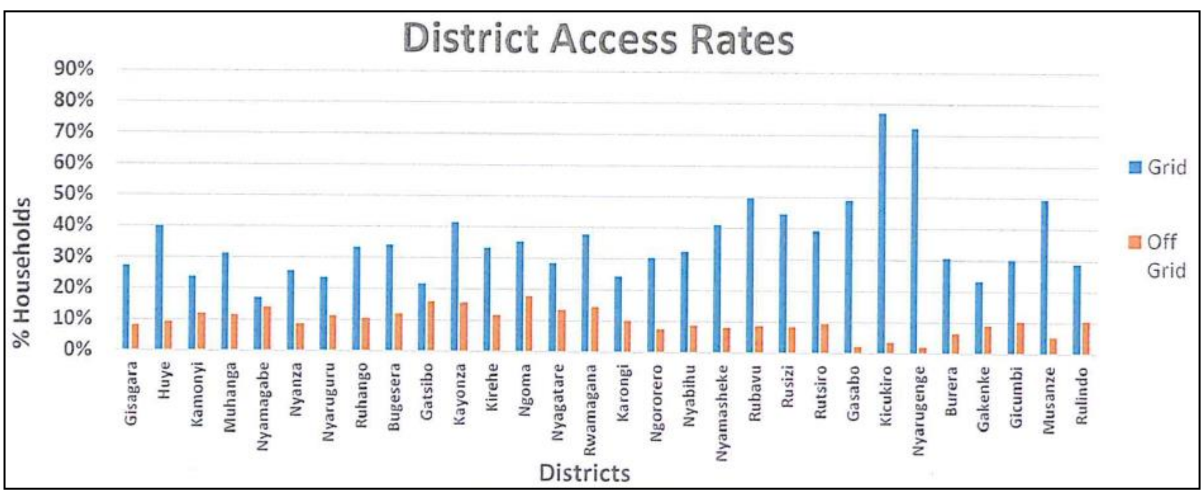

Figure7: *On/Off grids electricity connectivity in Rwanda*

As shown in figure 7, urban areas perform well in grid connectivity due to densification which allows easy grid filling in connections. In rural areas off grid connections are concentrated according to the rural electrification strategy and the national electrification programme. Generation of power plants in Rwanda poses several challenges. In hydropower production, which is primarily silted in river catchments, great reduction of flowing water during the dry season, cascading of the hydropower project, the everyday life of human activities and lack of integrated planning among water users (upstream and downstream). More generations of solar power plants are not available during the evening hours when capacity generation is most needed. Lack of incorporation of energy storage facilities to improve power production at night by using the solar energy stored during daytime. The land (Rwamagana solar power plant) is covered by various forms of solar collectors, and then the minimum required sun's rays cannot reach the surface of the earth. This will certainly kill the earth's vegetation and may also survive the bacteria that are destroyed by the sun's rays, giving rise to new kinds of health problems. To date, 2,464 Solar Water Heaters (SWHs) have been installed in various households across the country, and SWH systems are using energy from the sun (solar radiation) to heat water that can be used for bathing as well as washing clothes and most typical household appliances. Solar water heaters are simple, easy to install and connected to the existing system of water supply. Water heating is currently the home's third-largest user of electricity. There is a decrease in reliance on electricity, fossil or biomass fuel for heating water with a solar water heater, and saving money and improving the climate. In particular, a SWH could help save money if your home used electricity, due to the increasing cost of these sources of energy. The thermal power plant uses two types of fuel; the first is light fuel oil (LFO) and the second is Heavy Fuel Oil (HFO) to generate electricity of approximately 20MW when it runs at full load. It is equipped with three internal combustion engines (Wartsila 18V32) of which each drives the generator connected to it in order to generate 7MW. However, the engines are primarily designed to run with HFO and LFO as a backup. This is because of financial means as HFO is much cheaper than LFO. The plant is installed with other auxiliaries mainly for fuel storage, fuel treatment and lubricating oil storage and treatments. The thermal power plant has serious impacts on land, soil, air and various social impacts the thermal power plant is also said to emit large amounts of mercury and generate an enormous quantity of fly ash which destroys the surrounding environment. By calculating gas quantity from power plants, since we know the quantity of HFO consumption, we can then multiply by its respective emission factor to get the total emissions from the plant over a specific period of time. In 2018 annual CO_2 emissions by the user side, but without including the transmission and distribution losses were 91,792,393 $kgCO_2$/year. In 2019 up to October CO_2 emissions were 113,497,539 $kgCO_2$. Rwanda's electricity grid system is divided into high voltage - HV (110kV and 220kV) medium voltage MV (15kV and 30kV) and low voltage-LV (0.4kV). The entire grid system is being managed using the supervisory control and data acquisition (SCADA) system. At id stands 777.4 Km of high voltage transmission lines had been laid, evacuating power from various points of generation across the country and facilitating regional interconnectivity. This represents an increase of 4.3% compared to 2017 (744.7km) and 35.4% compared to 2016 (573.9Km). The total network that has been laid so far, 480.4km (64.5 percent) is 110kv, and 264.3km (35.5 percent) are 220kv. Note that the power plants vary from one another, depending on the technology used to produce the power. This means that each power plant has its manuals of operation and maintenance, depending on the manufacturer of technology and equipment. Each plant must request a maintenance plan prior to the beginning of the new fiscal year which includes plant outage. Any workers must be aware of and use Personal Protective Equipment in their everyday activities when entering the power plant or working inside it. Plant workers are given daily information, inspection and instruction on safe operations and how to prevent workplace injuries to plant operators.

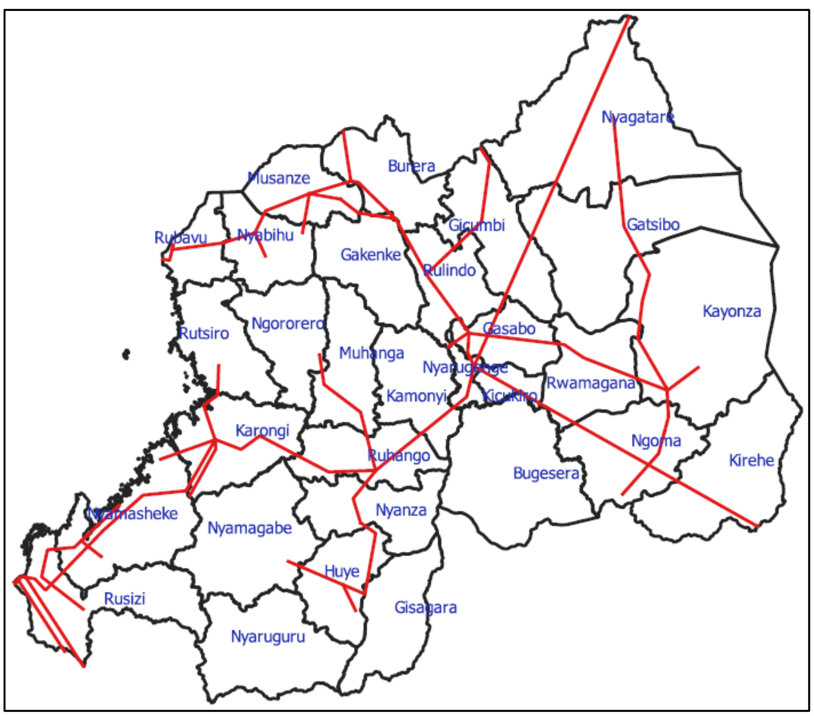

Figure 8: *Rwanda Electricity Transmission Networks*

6. Conclusions

This study begins with a review of the literature, focusing on methods of physical inventory, development of power plants and geographical locations. The quantitative data analysis of all power plants was carried out and it was found that hydropower plants make up nearly 50 per cent of the country's total electricity supply. Both the existing (operational) and planned power plants are growing and satisfying the countrywide demand for electricity. Through the country's energy mix, increasing the use of renewable energy technologies and optimizing the availability of electricity supply to satisfy peak demand, and minimizing the risk of producing excess power can be used. Rwanda's government has taken an appropriate policy decision to diversify power sources from the dominant conventional grid to include even off-grid connection. Subsequently, households far from the operational / planned national grid coverage were encouraged to use alternative, cheaper connections such as mini-grid and solar photovoltaic (PV) to reduce the cost of access to electricity while relieving restrictions on historical government subsidies and the policy is rigid under severe implementation. Environmental impact assessment should be well-defined as a precondition for any new or planned power generation projects.

7. Data Availability

All relevant data and information (existing/operational, planned power plants, geographical information and plant performances) are available via data records repository of the Rwanda Energy holding company: https://www.reg.rw/index.php?id=2, Available at: URL (Accessed, 20, august 2020).

References

[1] Ministry of infrastructure, Energy sector strategic plan, 2018/19 - 2023/24

[2] Rwanda least cost power development plant (LCPDP), 2019 – 2040

[3] REG/EDCL, Transmission Network Master Plan for Rwanda, June_2019

[4] http://epdrwanda.com/, Available at : URL(Accessed, 13, August 2020)

[5] Ballou, R.H. (2005) Expressing Inventory Control Policy in the Turnover Curve, Journal of Business Logistics, 26(2), pp.143-164

[6] Boute, R.; Lambrecht, M.; Lambrechts, O.; Sterckx, P. (2007) An analysis of inventory turnover in the Belgian manufacturing industry, wholesale and retail and the financial impact on inventory reduction, [Online], Available at: https://lirias.kuleuven.be/ bitstream/123456789/175504/1/KBI_0725.pdf, [Accessed 14 August 2020]

[7] Felea, M. (2008), The role of inventory in the supply chain, Amfiteatru Economic, 24, p.113

[8] Hada, T. (2009) The Financial Management of the Enterprise, Aeternitas Publishing, Alba Iulia, pp.132-134

[9] Müller, M. (2003) Essentials of inventory management, AMACOM American Management, pp. 2-4

[10] http://www.reg.rw/what-we-do/generation/, Available at : URL(Accessed, 18, August 2020)

[11] http://www.mininfra.gov.rw/index.php?id=83, Available at : URL (Accessed, 15, August 2020)

[12] Samantha Islam, S.G. Ponnambalam, Hon Loong Lam (2016), Review on Life Cycle Inventory: Methods, Examples and Applications, Journal of Cleaner Production

[13] https://www.mininfra.gov.rw/index.php?id=generation, Available at: URL(Accessed, 19, August 2020)

[14] B V Babu, Life Cycle Inventory Analysis (LCIA), Life Cycle Assessment & Life Cycle Management Methodologies, The Boulevard Hotel, Kuala Lumpur, 4th – 5th December, 2006

[15] MININFRA (20018), Energy sector strategic plan, 2018/19 - 2023/24, Ministry of Infrastructure, Kigali, Rwanda.