UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

Title: **Contribution of renewable energy in reduction of CO_2 emissions in Rwanda:**

Case study: Jabana Thermal power plant

By UWITONZE Adeline

Reference number: 221000871

A dissertation submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD) in the College of Science and Technology, University of Rwanda

In partial fulfillment of the requirement for the degree of MASTERS OF SCIENCE IN ELECTRICAL POWER SYSTEMS (EPS)

Advisor: Dr. KAYIBANDA Venant

October, 2022

Kigali-Rwanda

UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

DECLARATION

I, the undersigned, declare that this Thesis is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials that will be used for the thesis work will have been fully acknowledged.

Names: UWITONZE Adeline

Signature

Date of Submission: ___27/___10___/2022

This thesis has been submitted for examination with my approval as a university advisor.

Thesis Advisor

Dr. KAYIBANDA Venant Signature

DEDICATION

This thesis is in honor of my lovely husband, Mr. Ildephonse Ayabagabo, my Children Ineza Mugabo Ange Dorine and Isingizwe Mugabo Doriane and my family members for being there for me all through my studies. May the Almighty God bless you so much!

ACKNOLEDGEMENT

This thesis was made possible thanks to the advice and support of different others. I want to thank my supervisors Dr Venant KAYIBANDA from the bottom of my heart
who accepted to provide me unlimited support and guidance in formulating my topic and developing it from the beginning to the end. Several discussions with him and his comments on this thesis have been very illuminating.

I sincerely appreciate the lecturers of the University of Rwanda ACE-ESD in general, and especially those of Electrical power system for their unequalled effort to provide us a solid academic and social knowledge and thus promise us a bright future. Heartwarming thanks are addressed to my Husband, and daughters. My studies would not be possible without any financial and moral support provided by them. Thank you very much for your endless love and gratifying my studies.

Last, but not least, I would like to make acknowledgement to my classmates at University of Rwanda ACE-ESD for their encouragements Thank you for your understanding and endless unity during our studies.

God bless you all!!!!

Contents

List of tables

List of figures

ABREVIATIONS

TWh: Terawatt-hour

CO_2: Carbon dioxide

Mt: Megaton

GHGEs: Greenhouses Gases Emissions

GWh: Gig watt-hour

N_2O: Nitrogen oxide

tCO_2 eq:Carbon dioxide equivalent

PV: Photovoltaic

ASE: Community-assisted Access to Sustainable Energy

EDPRS: Economic Development and Poverty Reduction Strategy

MWp: Mega Watt peak

HESs): Hybrid energy system

MPPT:Maximum power Point Tracker

E_{DEG}:Energy Generator Diesel

DPP:Diesel Power plant

Abstract

The solar PV system is the renewable energy offered in this project as a means of reducing carbon dioxide emissions at the Jabana thermal power plant. It was a hybrid power system model with a diesel generator and solar panels. The meteorological agency provided the information on sun irradiation, and the Jabana thermal plant provided information on power generated and the amount of fuel burned by the generators. Homer software was used in simulation results that proposed PV-Diesel generator system is attractive to reduce C02 emissions by 46% when compared to diesel system. Additionally, the study calculated the cost of operation and the cost of energy per unit. The diesel-photovoltaic system was found to be more appealing in terms of lowering carbon dioxide levels and generating energy at a lower cost. And power generated because this proposed hybrid system contribute 30-40% of the total generation.

CHAPTER 1 INTRODUCTION

1.1. Background

Subsequently to industrial revolution, worldwide energy generation and consumption has risen considerably due to population growth and economic development[1].Because of the worlds rapid population expansion, economic development and worldwide economic integration, human activities have directly or indirectly put more stress on the environment in the world.[2]. The share of world's electricity generation by source shows that in 1973 oil contributed 24.8%, natural gas contributed 12.1%, nuclear contributed 3.3%, hydro contributed 20.9%, non-hydro renewables and waste contributed 0.6%, and coal contributed 38.3% with a total electrical energy generated of 6131TWh while in 2019 oil contributed 2.8%, natural gas contributed 23.6%, nuclear contributed 10.4%, hydro contributed 15.7%, non-hydro renewables and waste contributed 10.8% and coal contributed 36.7%, with a total electrical energy generated of 26,936TWh[3]. Also, pollutant emissions, particularly carbon dioxide (CO_2), have risen significantly as a result, causing severe environmental issues such as climate change and drawing increasing attention from the public, governments, and other stakeholders[1]. Fuel share of CO_2 emissions from fuel combustion shows that in 1973 oil contributed 49.9%, natural gas contributed 14.4%, and coal contributed 35.7% with a total CO_2 emission of 15,461Mt while in 2019 oil contributed 33.7%, natural gas contributed 21.6%, coal contributed 44.0% and other contributed 0.7% with a total CO_2 emission of 33,622Mt [4].

Particularly in Rwanda; by the end of June 2021 the total generated energy was 954.7GWh, the energy generated by source shows that hydro generated 494.4GWh which corresponds to 51.8% in energy mix, methane generated 206.8GWh which correspond to 21.7%, thermal generated 92.7GWh which corresponds to 9.7%, solar generated 18.1GWh which corresponds to 1.9%, peat generated 30.6GWh which corresponds to 3.2%, import energy was 29.7GWh which correspond to 3.1% and shared generated energy was 82.3GWh which corresponds to 8.6%[5]. The relationship between energy and issue of CO_2 emissions in Rwanda is that the energy sector, excluding Forest and Other Land Use counts the second largest contributor to Rwanda's overall Green House Gas emissions (GHGEs). Most of energy sector's GHGEs are CO_2 with total emissions of 1,722.94Gg, CH_4 with total emissions of 455Gg and N_2O with total emissions of 176.9Gg in 2018 and those gases result from the fuel combustion activities. During this year, the total GHG emitted was 6,755.6Gg while it was 4034.5Gg in 2006 and this shows that during this period of time there have been an increase of 40.28% of Green House Gas emissions [7]

The four main source of CO_2 emissions are direct energy related emissions which are emissions from combustion of fossil fuels to produce process heat in the form of hot water, steam, and direct heat; the second is indirect energy related emissions which are emissions from electricity and district heat generation for some industrial operations, motors, and auxiliary applications; the third is process emissions which is CO_2 released as a result of industrial processes, such as CO_2 released from the use of anodes in aluminium manufacture and the fourth one is product life cycle emission such as fugitive emissions from the use of solvents, lubricants, and other substances, and cremation of end-of-life plastic garbage [6]

1.2. The problem statement

In this era of rapid industrialization, economic growth has been the primary emphasis of many countries, which is directly tied to various causes they are said to be the cause of environmental deterioration. As a result, the growing environmental challenges in the last few decades have received a lot of attention. CO_2 emissions are commonly regarded as the global most t significant environmental concern, resulting from a complex interaction between three key factors, including economic growth, energy use and environment cause a risk to human life and the sustainability of the ecosystem. Energy is widely regarded as the most significant environmental deteriorating element [6]. This fact has drawn increasing attention since it has the potential to trigger severe environmental issues such as global warming [1]. The Paris Climate Agreement calls on countries to enhance limiting the century,s global temperature increase to well under 2^0Cas a result of their collective response to the threat of climate change over prior to industrialization, and to pursue efforts to keep it even lower at 1.5 °C. To meet the 1.5-degree target, a concerted effort will be needed in different sectors of the economy to get near zero dioxide carbon of emissions by the later decades of this century [6].

In Rwanda, reduction of Green House Gas emissions was divided into two different components. The first one is unconditional contribution which is to the reduction of 16 % in the year 2030; equivalent to an estimated mitigation level of 1.9 million tonnes of carbon dioxide
equivalent (tCO_2 eq.) in that year. This is an unconditional target, based on domestically supported and implemented mitigation measures and policies. The second is conditional contribution which is an additional reduction of 22 % in the year 2030; equivalent to an estimated mitigation level of 2.7 million tCO2e in that year. This represents an additional targeted contribution, based on the provision of international support and funding. The combined unconditional and conditional

contribution is therefore a 38% reduction in GHG emissions compared in 2030, equivalent to an estimated mitigation level of up to 4.6 million tCO2e in 2030 [7]. Therefore, this proposal focuses on feasibility study of Contribution of renewable energy in reduction of CO_2 emitted by Jabana thermal power plant.

1.3. Objectives

1.3.1. Main objective

The main objective of this research work is to highlight the contribution of renewable energy in reduction of CO_2 emissions from Jabana Thermal power plant.

1.3.2. Specific Objective

(i) Identify conventional energy sources used in electrical energy generation.

ii) Assess CO_2 emitted by Jabana thermal power plant as energy source used for electrical energy generation.

iii) Suggest a hybrid system (combination of PV and thermal power plant) for replacing existing thermal power plant at Jabana.

1.4. Scope of study

This research will emphasize to the contribution of renewable energy especially solar PV system in reduction of CO_2 emitted by Jabana thermal Power Plant as one of the greenhouse gases which contribute to the global warming.

1. 5. Expected outcomes and Significance of the study

1. 5.1. Expected outcomes

The expected outcomes are:

(i) This research work will show the role of conventional energy source on dioxide carbon emissions and other Green House Gases and suggest other type of energy source which can be used instead of conventional energy source. This will be done by suggesting a hybrid PV-thermal power plant at Jabana thermal power plant and this will reduce CO_2 emissions and other Green House Gases.

(ii) Other anticipated results of this study is the decrease of operation and maintenance cost as solar PV panels which will be used for this hybrid do not require fuel and also the maintenance cost solar PV panels is low.

1. 5. Significance of the study

This research emphasize the role that renewable energy plays in reducing the amount of CO2 that the Jabana thermal power station emits. This will be done by suggesting other source of energy (renewable energy) which could be put into place instead of conventional energy source for the purpose of CO_2 emissions reduction in order to achieve national and global target of CO_2 emissions reduction. This feasibility study will come out with recommendations about a Hybrid system which can be used at Jabana thermal power station

CHAPTER 2 LITERATURE REVIEW

2.0. Introduction

Africa is already facing the significant consequences of climate change, and will only continue to do so as long as immediate action is not taken to defend the planet. The Rwandan Government, led by H.E. Paul Kagame, has consistently implemented green strategies to reduce negative impacts that Rwanda has on the environment. Rwanda has committed to the race to zero emissions, a global effort set out by the UN (UNFCC, Web). with the aim for participating regions to reduce their carbon impact, and secure an environmentally stable future. Even if Rwanda's contribution to global greenhouse gas emissions is relatively small, emissions from deforestation, agriculture, and land use, combined with strong expected emission growth from expected economic development and energy use, are significant enough within Rwanda's carbon footprint to demand a mitigation response. Therefore, In 2020, Rwanda committed to reduce its emissions by 38% by the year 2030, this is equivalent to 4.6 million tons of carbon dioxide .

Rwanda's energy sector strategic plan (ESSP) assures that for economic expansion and increasing family access to electricity, an adequate supply of electricity is essential. Therefore, to meet the target of an additional 15% reserve margin for the increase power supply reliability, numerous pipeline projects including solar PV projects and geothermal energy projects have been discussed and developed, among others[7].

Energy sector faced a lot of problems in Rwanda. Those problems are as follows, as summarized in the IOB Evaluation No. 396 of August 2014 by the Ministry of Foreign Affairs of the Dutch:

The gradually and growing more urbanised population, coupled with increasing per capita income caused to more demand of energy for cooking

> and other operations requiring the use of power. There has been a disproportionate rise in demand for fuelwood because wood and charcoal are the primary sources of energy in urban and semi-urban areas. Urban regions have few other energy sources, and biogas is seldom practical there. Imported LPG and electricity are also too expensive for most homes. The government's effort to establish eucalyptus plantations to assure a supply of fuelwood has been successful.

2.1 Conventional energy sources used in Rwanda

Rwanda has access to fossil fuels and biomass as energy sources. Biogas, peat, wood, wood for charcoal, methane gas, agricultural waste, and biogas are all conventional energy sources in Rwanda. Peat and petroleum derivatives account for around 85% of the energy usage in the nation and 5% of its GDP. [8].

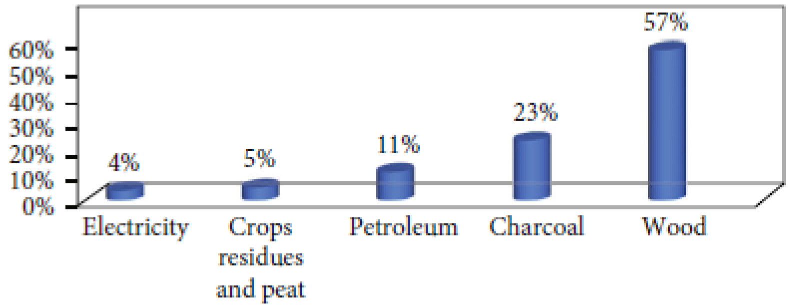

Figure2.1: Main energy sources[9]

The energy sources from the figure 2.1 have been changing from 2016, whereby we can now experience conventional energy sources and some off-grid power systems such as batteries.

Rwanda is largely dependent on imported petroleum products. Hydrocarbons serve as a source of electricity by powering diesel generators, and are also used in the transport sector. About 42 per cent of the electricity produced in Rwanda is produced by diesel generators. Information on the petroleum energy sources is scanty and is therefore not included here.

About 85% of the primary energy used in Rwanda is derived from biomass, which dominates the country's energy balance. Although the reliance on biomass has decreased in the last 20 years from 95% to 85%, the ratio is still viewed as being too high and damaging to forest resources. [10].

Biomass is the most conventional energy source in Rwanda. About 300,000 people are involved in the biomass business - farmers, charcoal producers, transporters and commercial people (MININFRA, 2008b). About 84 people are currently employed in the SNV biogas program which is expected to grow. Many entrepreneurs are involved in construction, maintenance of biogas systems and training and many families have already benefited from this program (MININFRA, 2007). Community-assisted Access to Sustainable Energy (CASE) project focuses on poor and peri urban people and is likely to reduce the gap between biomass supply and demand for 24,000 households in Nyamagabe, Nyaruguru, Gisagara and Huye districts.

Half the number of households using traditional cooking technologies to achieve a sustainable balance between supply and demand of biomass through promotion of most energy efficient technologies, and in line with the targets of NST-1The development in urbanization supports the delivery of governmental interventions and measures to remove obstacles to the use of alternative fuels, such as biogas and LPG. With an improved coordination between stakeholders, prioritizing the biomass subsector will ensure that progress is made at a substantially faster rate. [7].

In Rwanda there is also the thermal power plant, and this power plant use fossil fuels to generate electricity. The thermal power plant has substantial negative effects on the environment, society, and the economy. Additionally, it's thought that the thermal power plant emits a lot of mercury and generates a lot of fly ash, both of which are harmful to the environment.. Natural gas, oil, and coal are all examples of fossil fuels, account for around 90% of worldwide energy use[11].CO2 emissions from fossil fuel burning have surpassed all other sources of man-made greenhouse gas (GHG) emissions. Around 14 million m3 of water are used annually by a new 500 MW thermal power station. [12].

Rwanda currently has 9 thermal power plants, including those that run on diesel and those that run on alternative fuels like methane and peat. These power stations presently generate 51% of Rwanda's total electricity. Considering that diesel is the most expensive type of fuel, all efforts to develop energy production are aimed at lowering its percentage in the energy mix.

2.2 Renewable and reliable energy sources

2.2.1 Generalities on renewable energy

Energy policies of the country give special attention to the use of modern, clean and energy efficient technologies[13] Despite having a large potential for energy resources, Rwanda suffers from an energy shortage. [14]. Apart from Biomass energy, geothermal and solar PVs are renewable energy sources that have been discovered and installed in Rwanda. However, these two types of renewable energy sources are not exploited at a level of satisfying the community’s energy demand.

Rwanda’s household access to electricity has increased by 69.68% in March,2022, Including 49.03% connected to the national grid and 20.65% accessing through off-grid systems(mainly solar) [34].Many reasons for this grid connectivity failure may also be linked with the geographical locations of communities (example in remote villages where the grid does not reach yet) or incapability of families to afford the cost of electricity which is generally affordable to households if we consider electricity tariffs set by Rwanda Energy Group

(REG).[35] Figures 2.2; 2.3 and 2.4 highlight the evolution of electricity generation capacity, transmission and access on the period from 2010 to 2022. However, with the National Strategy for Transformation (NST-1), the targets have been set, among them are the electricity generation capacity to expand from 238.46MW to 556MW; access to increase from 68.48% to 100% using off-grid power systems, solar PV, and other renewable energy sources; and expanding transmission and reinforced to ensure universal access by 2024. Nonetheless, data for the evolution of power transmission are limited to 2017 although developments have been considerably made in the sector.

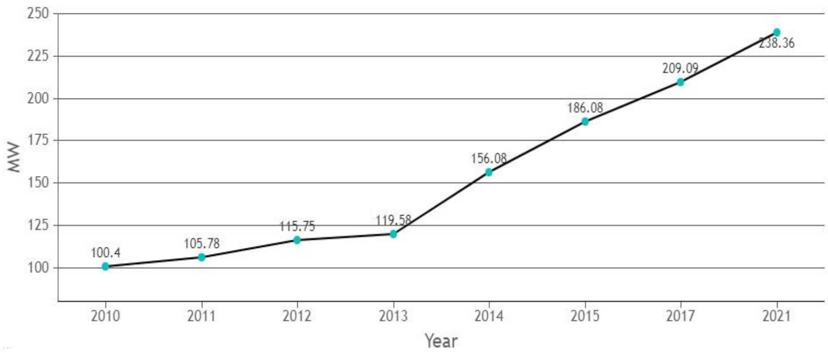

Figure2.2. Evolution of the installed electricity capacity(Mw)

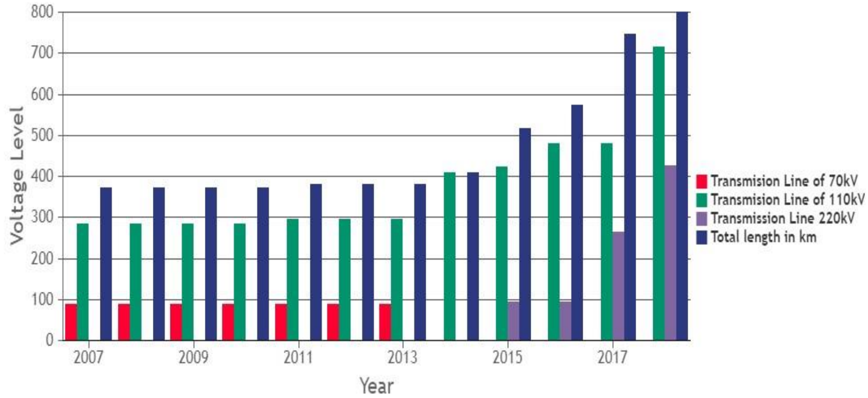

Figure 2.3 Evolution of the power transmission network(km)

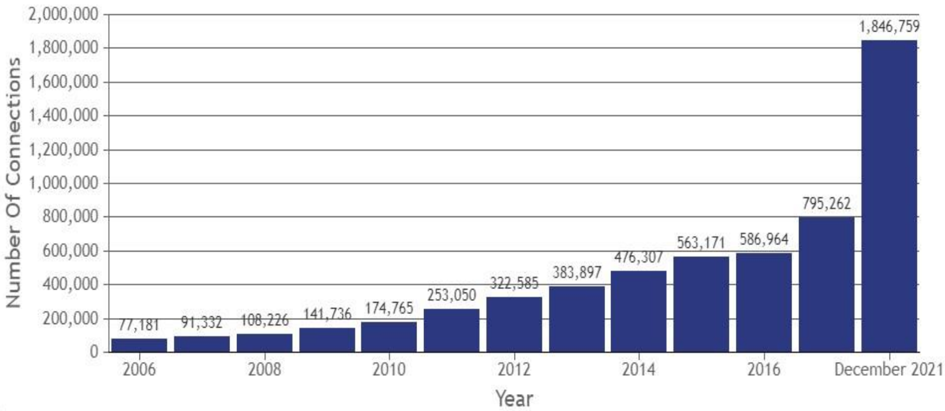

Figure 2.4: Evolutions of connections (Nr of population)

Numerous studies on the availability and use of electricity in Rwanda have been conducted, and some crucial technological requirements for the Rwandan power industry have been discussed. These include advanced metering infrastructure, advanced distribution automation, intelligent universal transformers, Demand management, demand response, and open automated demand response standards for distributed energy resources, integration of electrical vehicles on a massive scale (EV), and large-scale integration of renewable energy sources.

2.2.2 Solar Energy

Africa, which has the lowest electrification rate in the world, is reinventing itself to give its people a better future. Attention from all over the world is being focused on international financing to speed up rural electrification powered by off-grid solar systems and global renewable energy agencies[15].

Solar PV systems are one of the powerful sources of electricity that Rwanda eyes in the wake of combating carbon emissions towards a green economy Rwanda and a green eco-environment. The Agahozo- Shalom Youth Village (ASYV) located in Rwamagana district in Eastern Rwanda is the first utility-scale, grid-connected, commercial solar field in East Africa. The field is 8.5 MW of grid-connected power to 15,000 homes and it increased Rwanda's generation capacity by 6% [16]; that’s why some land in different regions is being leased to house solar facility.

Figure 2.5:Agahozo shalom youth village

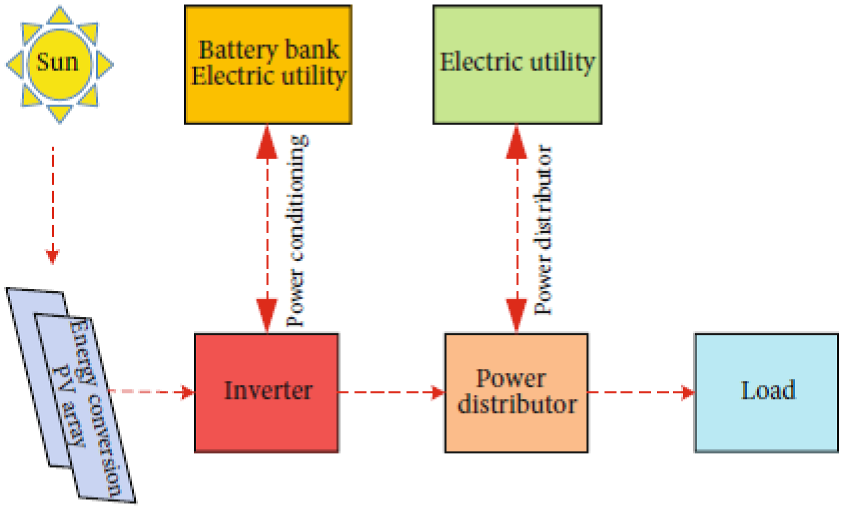

Figure 2.6:Solar PV power conversion

The ASYV is a residential community in Rural Rwanda. The CPP has a peak output capacity of 8.5 MWp consisting of 28,340 solar PV modules and covering 16 hectares. The project had net electricity of 15,275 MWh for the first period and the first year of operation of 15,552 MWh. The solar field at the ASYV in Rwanda embodies a range of causes: it helps the long-term development sustainability, well for the environment, it generates local job opportunities employment, education and it empowers the country with access to electricity, which will be the results of benefits for the Rwandan population. The project is expected to achieve average annual emission reductions of about 9,470 tCO_2e and a total of 66,289 tCO_2e during the first crediting period; which marks a of state-of-the-art technology in utility-scale power generation from solar PV sources [16].

Some other Solar PV projects have been installed with their respective capacities as described in the table below:

Table 2.1: Total Number of solar power plants in Rwanda and their capacity (MW) [9]

N	Plant Name	Capacity (MW)
1	solar power plant in Jali	0.25
2	solar power plant in Ndera	0.15
3	solar power plant in Nyamata	0.03
4	solar power plant in Nasho	3.3
5	Gigawatt Global Rwamagana	8.5

Rural communities' social and economic change has accelerated because to off-grid solar. [15]. Solar home systems have also been studied and proposed for more economic and carbon-free solutions to the livelihood of communities[17]. and especially for refugee camps in Rwanda through an environmental, political, economic, social, technological, legal, and societal lens (PESTLE) setting and analysis to address the limited access to electricity[18].

2.2.3 Potential of solar energy in Rwanda

Rwanda benefits greatly from solar energy; even during the wet seasons, there is every day and ample sunshine, particularly in the Eastern province, which has high irradiance values. On the tilted surface, the average daily global solar irradiation is 5.2 kWh per m^2 in a day. The monthly average daily worldwide irradiance are between from 4.8 kWh/ m2 (location Burera, May) to 5.8 kWh/m2 day (location Nyanza, July), indicating that solar energy development has a lot of potential[19]. figure 2,7 shows the Global horizontal irradiation map for different districts of Rwanda

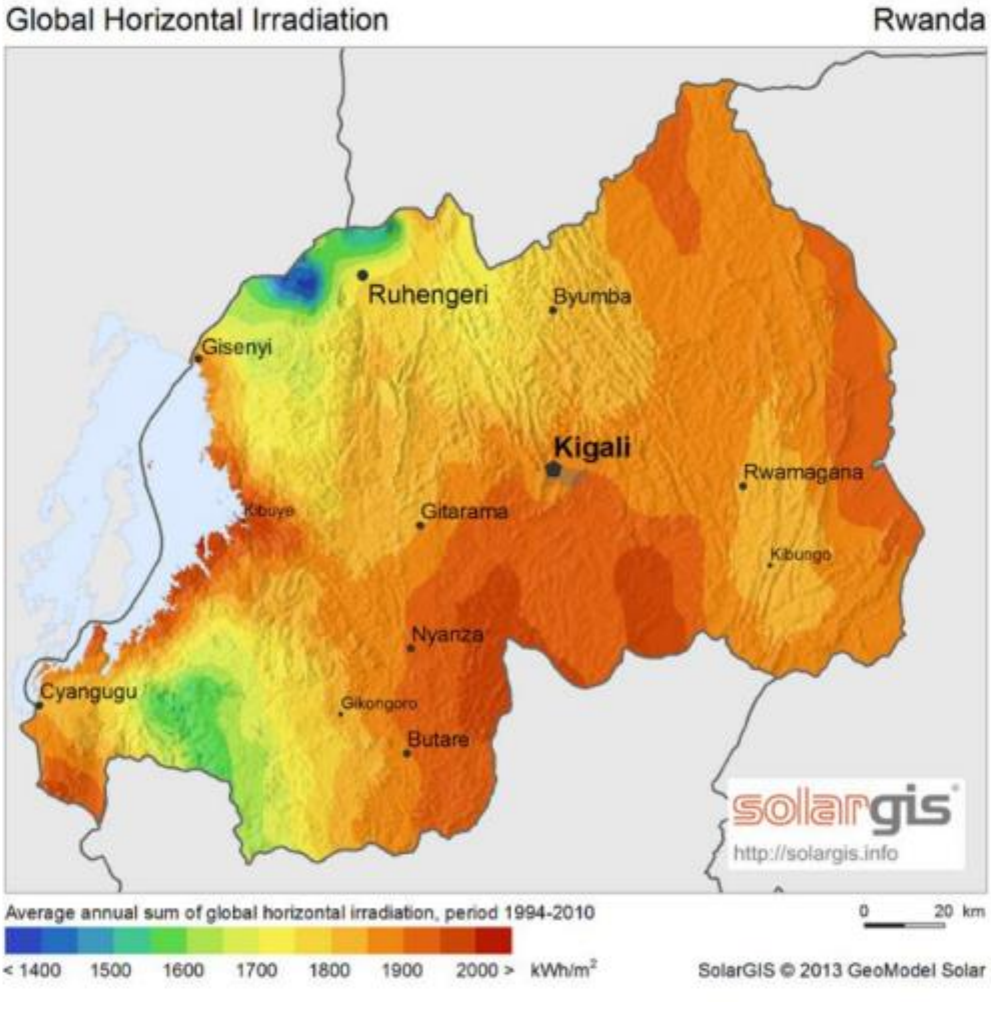

Figure 2.7:Global horizontal irradiation map for different districts of Rwanda

2.2.4 Geothermal energy

Geothermal resources, consisting in the heat contained in the Earth crust, are presently exploited for both electric power generation and for direct uses. Apart for the utilization of low temperature resources (<100°C) only made for direct uses, the generation of electric energy is made from medium (between 100°C and 200°C) and high (>200°) temperature geothermal systems [13].

The process of developing geothermal resources is only beginning, and exploration drilling is already being done to show that there is geothermal potential. Rwanda is believed to have a geothermal potential which is estimated to be in excess of 300 MW, due to the country's proximity to the geothermal resource of the Great Rift Valley[13].

Researches and investigations have indicated that Rwanda boasts thermal waters with temperatures of up to 150°C, and the most promising geothermal areas are Karisimbi and Kinigi where the Government of Rwanda considers a commercially viable geothermal resource for power generation using both binary and condensing steam turbines [13], not neglecting the resurgence of Bugarama thermal potential.

Figure 2.8: location map of the most prospective zones of geothermal

The Bugarama geothermal prospect is located in the Western Province of Rwanda. The geothermal manifestations in this area are hot and warm springs and travertine deposits, which is being mined as feedstock for a nearby cement factory. This prospect probably extends into Burundi and the Democratic Republic of Congo. No detailed geo-scientific work has been carried out in this area so far. A regional geothermal exploration study funded by EU has started in November 2013 for the three countries, Democratic Republic of Congo, Burundi and Rwanda. The exploration study will conclude with location of targets for deep exploratory wells drilling. The project is financed by the European Union and the consultancy firm hired for this project is Reykjavik Geothermal (RG). Great Lakes Energy Agency (EGL) is mandated for the implementation of this regional project [22].

According to Rwandan Ministry of Infrastructure, the development of Geothermal Resources has been given the highest priority over Economic Development and Poverty Reduction Strategy second phase period (EDPRS II) and among envisaged developments there are: 10 MW from Test Generation site at Kinigi and 10 MW from Test Generation site at Karisimbi with 50 MW of production scale generation at Kinigi/Karisimbi[13].

Geothermal energy has the potential to create electricity at a cost four times lower than Rwanda's existing diesel-generated electricity. Oil-fueled power plants might also be replaced by it. [38].

Geothermal power generation has GHG emissions over its lifecycle comparable to those of other renewables and definitely lower than fossil fuels fewer than 50 eq/kWh. Despite a limited role in the energy mix of sub-Saharan countries from now till 2040, geothermal energy is expected by IEA (2019) to have a huge development in East Africa thanks to the very large predicted increment of overall power generation (about 10 times).

2.3 Towards environment sustainability and CO_2-Free Rwanda

Rwanda also has fairly low carbon intensity when energy related emissions only are considered (478 tCO2/$Mill GDP), though again these rise significantly when GHG emissions from agriculture and land use change are included to 1864 tCO2/$Mill GDP (excluding forestry sinks). Carbon intensity is projected to decrease slightly by 2020, though there is very high uncertainty in this forecast, due to the agricultural sector projections. However, Rwanda does not have a large industrial or energy base, and so intensity targets do not really make sense: agricultural emissions dominate carbon emissions and the future projections and intensity in the agricultural sector are very unclear. Energy emissions are dominated by transport, which is a difficult sector to tackle with intensity goals. Therefore any specific intensity plans would be highly uncertain [24].

The relationship between Rwanda's population, industrialization, per-capita GDP, and carbon dioxide emissions has been of great concern in recent years. Notably, Rwandan population plays a critical role in the country's economic growth rate, industrialization; in the form of labour and carbon dioxide emissions; people's actions or inactions that affect environmental pollution either positively or negatively (a 1% increase in GDP per capita may decrease carbon dioxide emissions by 1.45%, while a 1% increase in industrialization can increase carbon dioxide emissions by 1.64% in the long-run). As a policy implication, environmental related institutions should adopt the people-centred approaches towards climate change adaptations, early warnings and climate change impact reductions[25].

The effects of air pollution on the environment, economy, and health of people living in affected countries cannot be overstated. The E-drone is a new technology that can be used to remove air pollutants. Every hour, it flies up to a predetermined altitude (Ealtitude), where it measures the air pollutants. If any of them are above the acceptable threshold, it then applies on-board pollution abatement remedies before descending to the ground.[26] .

The 1980–2010 period was used to examine the short- and long-term relationships between CO2 emissions, GDP, renewable energy consumption, and international trade for a panel of 24 sub-Saharan African countries. The results showed that there was a bidirectional causality between emissions and economic growth, a bidirectional causality between emissions and real exports, a unidirectional causality from real imports to emissions, and a unidirectional causality between emissions and real imports. There is an indirect short-run causal relationship between emissions and renewable energy, as well as between GDP and renewable energy. The error correction term is statistically significant for commerce, use of renewable energy, and emissions over the long run.[27] .

2.4. Related work

[28] In their research on "Impact of energy intensity, renewable energy, and economic growth on CO2 emissions: Evidence from Africa across regions and income levels." They have shown that African counted about 1.9% to the total global emissions in 1973. To ignore its negative effect led to significant environmental deterioration and increasing trends with more increment rate the attention has been taken decrease CO2 emissions across regions and regional economic communities. They suggest to establish renewable energy projects based on power pools (Central, West, Southern, and Eastern) associated with cross-border power trades these renewable energy are hydropower and solar energy and they are playing a significant role to reduce energy demand, energy poverty, and emissions in the continent. After analyzing data from Energy Information Administration database EIA . The results suggest that energy intensity and economic growth led to CO2 emissions, while renewable energy reduces CO2

emissions across the regions. Other results obtained show that renewable energy is the most contributing factor for CO2 reduction due to its low variations.

[29] In their research on**”** Renewable energy, CO2 emissions and economic growth in sub-Saharan Africa: Does institutional quality matter? In their research they showed the relationship between institutions, renewables energy, C02 emissions and economic growth for 45 sub-Saharan Africa countries using annual data over the period 1960-2017. They showed that the rising level of global CO2 emissions is fossil fuel consumption In order to decrease carbon dioxide emissions, energy from fossil fuel should be replaced by clean renewable energy source for sustainable development. The most efficient and ideal substitute for fossil fuels, as well as the most commonly acknowledged method of reducing climate change, has been renewable energy. The findings imply that while economic expansion has little impact on institutions, CO2 emissions harm them. The findings also show a considerable decrease in dioxide carbon because of integration of renewable energy.

[23] In their research on” Does the use of renewable energy and globalization help reduce carbon emissions in Sub-Saharan Africa?” Using information from 46 Sub-Saharan African nations, this study investigates the effects of globalization and renewable energy on carbon emissions from 1980 to 2015. The research demonstrated that there is the reduction of carbon emissions by using fixed and random effects estimate approaches It was also shown that population expansion and economic development both contribute to rising carbon emissions. According to their study, there is less of an impact on the decrease of carbon emissions when institutional quality is evaluated in terms of regulation. Additionally, less carbon is released when more renewable energy is consumed.

[1] In their research on “Contribution of renewable energy consumption to CO2 emissions mitigation: a comparative analysis from the income levels’ perspective in the belt and road initiative (BRI) region” in their study they analyze the role of the Renewable Energy Consumption to mitigate the CO2 emissions from the income levels’ perspective for the belt and road initiative (BRI) region. The research divides the BRI region into four groups by the income levels(high, HI; upper middle, UM; lower middle, LM; lower, LO) during 1992–2014) The results show the REC of the BRI has an overall decreasing trend but the driving contribution to the CO2 growth except that the HI group’s REC has an obviously mitigating contribution of 2.09%. The number indicates that it is necessary and urgent to exploit and use renewable energy, especially in mid- and low-income countries due to the large potential of carbon mitigation. Besides, during 2010–2014, the energy intensity effects of different groups

were negative except for the low income group (positive, 5.47 million tonnes), which showed that some poor countries recently reduced CO2 emissions only by extensively using renewable energy but not enhancing the corresponding efficiency. Conversely, in other rich countries, people paid more attention to improve the energy-use efficiency to lower energy intensity.

[30] In their research on the energy, CO2 emissions impact of renewable energy development in China. The current objective of China's energy policy is to increase the installed capacity of power generated by wind, solar, and biomass. From 2010 to 2020, China's policy is to raise the output of renewable electricity from 95 TWh to 623 TWh or between (1.8% and 8.2%) the installation of renewable energy decreases carbon dioxide by 2%in 2010 and 2020. The results shows that rapid economic expansion increase price and consumption in 2015. the results shows that renewable energy decrease to 17%of carbon intensity.

2.5. The Gap

The issues with Rwanda's energy sector serve as the basis for the research's gap, and which need urgent response in the wake of the fight against CO_2 and GHG emissions for a Green Economy Rwanda. Considering the potential provided by the already installed solar PV plants, Rwanda being able to disseminate solar PV plants across the country shall bring much economic benefits in terms of sustainability and population. This will also move to contribute largely in the reduction of carbon emissions.

CHAPTER 3 RESEARCH METHODOLOGY

3.1. Introduction

To achieve the primary goal and secondary goals of this research; the detailed methodology has been developed. This chapter included techniques and methods that have been used for conducting this research. This was research design, research procedure, baseline survey undertaken to collect data and data collection methods used. Through literature review; information on how renewable energy helps to reduce CO2 emissions in Rwanda have been collected and fully analyzed. This has been covered in chapter two. It has been also discussing about tools and software that has been used to model renewable energy's contribution in reduction of carbon dioxide emissions in Rwanda.

3.2. Research Design

In order to come up with a good research design, the following points was taken into consideration: the kind of information needed to analyze how renewable energy reduced CO2 emissions in Rwanda, the project's location, and the procedures utilized to gather the information needed for this study.

3.3. Research procedure

A baseline survey was undertaken by the researcher at the Mateo Rwanda to establish the amount of solar irradiance of Jabana site as in this research I suggested to use solar PV system as renewable source which is available and which can contribute to the reduction of greenhouse gases. Other baseline survey that has been conducted is to know the quantity of power that is generated at Jabana thermal power plant and the fuel consumed. This information has served as starting data for the analysis the emissions of CO_2 at Jabana thermal power plant and to estimate a solar PV system that can be used instead of this thermal power plant.

3.4. Data collection methods and their instrument

For conducting this study, variety of data collection approaches were employed Includes analyses of the research on how renewable energy helps to reduce CO2 emissions, interviews and observations. To collect primary data, questionnaires, interviews, and observation were employed. Book reviews, Journals/articles and websites served as a source of secondary data. The information gained from literature review was utilized in order to gate information about the relationship between renewable energy and greenhouse gases emissions. . Monthly irradiance data was utilized in order to estimate a solar PV system which can be used instead of thermal power generation at Jabana. Interviewing and observation methods was also used where in July 2022 the visit to Jabana was conducted in order to conduct an interview with site engineer about the functionality of the plant, the power generated and the fuel consumption. Table 3.1; 3.2; 3.3 summarize the data collected.

Table 3.1: Solar irradiance of Jabana (data from Meteo Rwanda).

SN	Month	Solar radiation (W/m^2)/day	Solar radiation ($kWh/m^2/day$)
1	Jan	150.7	3.6
2	Feb	171.3	4.1
3	Mar	192.5	4.6
4	Apr	179.2	4.3
5	May	166.7	4.0
6	Jun	180.5	4.3
7	Jul	201.3	4.8
8	Aug	196.0	4.7
9	Sep	192.4	4.6
10	Oct	192.4	4.6
11	Nov	176.9	4.2
12	Dec	178.3	4.3
Average		181.5	4.4

Table 3.2: Sun hours of Jabana (data from Meteo Rwanda).

SN	Month	Mean sun hours
1	Jan	4.2
2	Feb	4.4
3	Mar	5.0

4	Apr	3.9
5	May	5.0
6	Jun	5.6
7	Jul	7.9
8	Aug	5.6
9	Sept	5.6
10	Oct	4.5
11	Nov	4.2
12	Dec	3.8
Average		5.0

Table 3.3: Power generated and fuel consumption at Jabana termal power plant.

Power generated (MW)	Number of generators	Fuel consumption per one machine per one kWh (g)	Fuel consumed by 3 machines per day (24hours) (l)
20.3	3	210	18000

3.5. Simulation tool

HOMER software was used for energy simulation, calculation of GHG emissions and economic analysis this software also was used to assess the quantity of CO2 emitted at Jabana thermal power plant and to suggest the hybrid PV-Diesel generator which can be used instead of using diesel only as this emit a big amount of CO2 and this contribute to the global warming

CHAPTER 4 DESIGN OF PV –DIESEL HYBRID SYSTEM

4.1 Introduction

Renewable energy is being pushed around the world due to rising energy demand and the depletion of conventional energy sources. In the age of modernization and economic development, energy is the vital ingredient. Its demand is steadily increasing with ever-increasing population along with improvement in living standards. The primary challenge now-a- days is to meet this growing energy demand without fully exhausting the resources to be used by future generations. In the last decade, earth's climate has changed and there have been rigorous debates on global warming by environmentalists and researchers. The major causes being pointed are the growth in world population and rapid industrialization, resulting in increased electricity demand which in turn was met by the conventional electricity sources like coal, oil and gas. Utilization of these conventional electricity sources contributes to the increase in greenhouse gases (GHGs) emissions, which brings hazard to our atmosphere. Renewable energy is being seen as an alternative to conventional sources because these are clean and environment friendly, thus may be helpful in mitigating GHG emissions. Therefore; different governments are proposing the renewable energy resources like photovoltaic (PV), wind, biomass, tidal waves, etc. as possible alternative to conventional fossil fuels [32]. Hybrid energy systems (HESs), which are able to get over the problem of intermittent and fluctuating RES supply, are created by integrating RESs with traditional fossil-fuel based generators. Compared to single energy sources, HESs can offer more cost-effective, dependable, and sustainable solutions. [33]. A hybrid system uses two or more power plants with different sources and a hybrid system is a way out to meet electricity needs. Hybrid systems are part of energy diversification. So in the general case, the primary purpose of the hybrid system is basically that in power systems with multiple sources. It could be said that there is a cross-subsidization or symbiosis-mutualism system. One system to another fulfills each other alternately or together, either simultaneously or at a partial time. The hybrid system is a solution to increase the generated and achievable power capacity and reduce carbon production [34]. In this section we discussed how to design a hybrid PV-diesel plant grid connected system which can be used instead of using only thermal power plant at Jabana so the sake of greenhouse gases emissions reduction.

4.2. Description of parameters

4.2.1. Load profile

The load profile of Jabana thermal power plant is presented in Figure 4.1 which has the capacity of 20.3MW and It has a constant connection to the grid. It is composed by three generators, each has 6.8MW capacity.

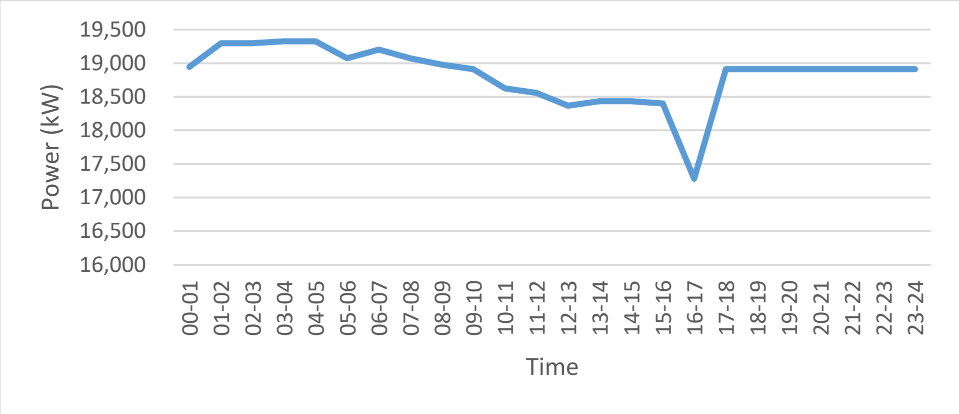

Figure 4.1: Jabana thermal power plant load curve

4.2.2. Solar radiation

Considering the available potential resource of renewable energy at Jabana power plant, the solar energy takes high priority. Figure 4.2 show the data from meteo of irradiance and time.

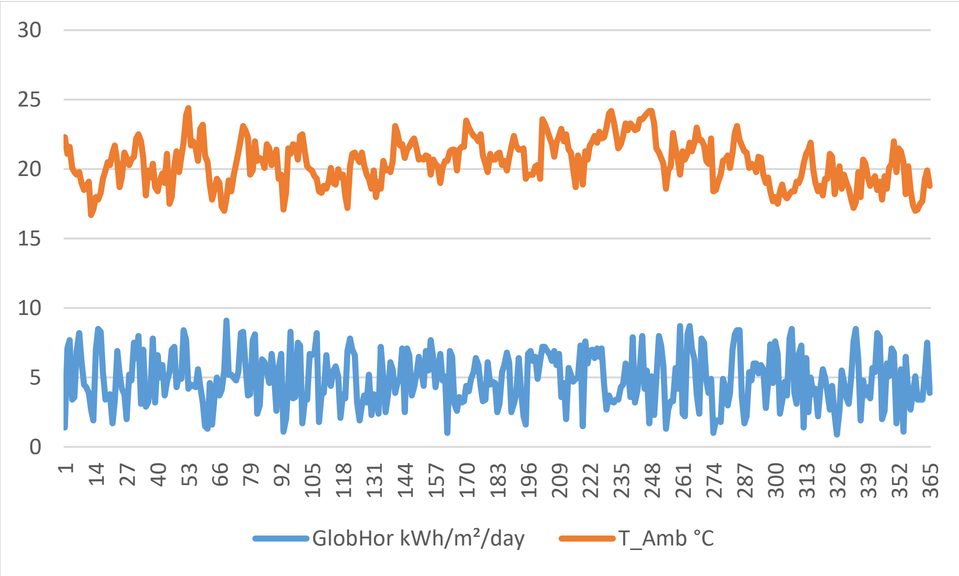

Figure 4.2 Jabana daily meteorology data

4.3 Hybrid system components

Diesel-PV system is a hybrid system comprises PV system with PV array, MPPT grid-tie inverter and two diesel generator as shown in Figure 4.3

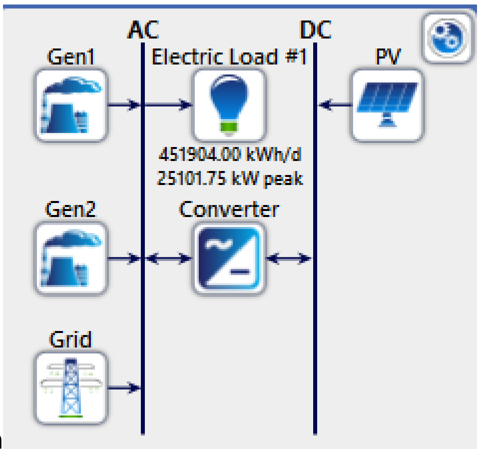

Figure 4.3: Block diagram of hybrid system

Figure 4.3: Block diagram of hybrid system

4.3.1Solar power system

The designed PV system is 9,000kWp based on the knowledge about the design of the solar PV system Mon crystalline solar panel type LONGI,SOLAR LR6-72HV 335M was selected the rating of this panel is 335 wp each and is installed on the area of 1.94 m^2 the reference temperature is 25^{o}C. The price of the PV panel was also taken into account when determining the ideal size. For the type of panel considered PV system consists of parallel and series connections of solar cell this make vertical and horizontal strings termed as PV Panel. For our PV system there is 26,866 modules. Those panel can be installed in available marchland nearby Jabana thermal power plant which occupy 5ha. The information was used in Homer software to see the contribution of PV in reduction of CO2 emissions

$$N_{PV} = \frac{Needed\ power(9{,}000{,}000W)}{Maximum\ power\ of\ panel(335W)} = 26{,}866\ modules$$

4.3.2. Converter

For power systems that need to utilize both AC and DC power, a converter is necessary to change DC to AC as inverter, when converting from AC to DC as a rectifier, or it can accomplish both tasks. 2000KWac central inverter was selected by the homer software with the minimum voltage of 800V, maximum voltage of 1500V.98% of efficiency was used.

4.3.3. Grid

The grid serves as the main hub for the distribution and exchange of power produced by both renewable and non-renewable energy sources.

4.3.4. Diesel Power Plant

The designed diesel generator was 6.8Mw each and the generic large Genset was chosen in HOMER software of 6800 Kw and the cost of 580,000 USD. This diesel will be used to assess the quantity of dioxide carbon emitted in the atmosphere

4.4 Energy Models

Energy model depends mainly on the economic feasibility and the proper sizing of the components in order to avoid outages as well as ensuring quality and reliability of supply. Energy design system looks into its sizing and the process of selecting the best components to provide cheap, efficient, reliable, environmentally friendly, and cost effective power supply. The techno-economic analysis looks at both environmental cost and the cheapest cost of energy produced by the system components. Designing a hybrid system would require correct components selection and sizing, with appropriate operation strategy. In energy systems, the sizing of the individual systems can be made in a variety of ways, depending upon the choice of parameters of interest. Energy models are employed as a supporting tool to develop energy strategies as well as outlining the likely future structure of the system under particular conditions. This helps to provide insights into the technological paths, structural evolution, and policies that should be followed [35].

4.4.1. Construction of a Model for Energy System Components

4.4.1.1. Solar-Photovoltaic Generator Modeling

The output energy of the PV generator (E_{PVG}) can be calculated using the solar radiation

$$E_{PVG} = G(t) X\ A\ X\ P\ X\ \eta_{PVG} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4{,}1)$$

The E_{PVG} (t) is energy output hourly from PV system (Wh), G(t) is the hourly radiation expressed in kWh/m2, A is the surface expressed in (m2), P level of PV penetration, and η PVG is the PV efficiency generator. [34].

4.4.1.2. Diesel generator modeling.

The following expression describes the amount of energy generator for a diesel (E_{DEG}) with rated power output (P_{DEG}) produces each hour:

$$E_{(DEG)}(t) = P_{DEG}(t)\eta_{(DEG)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Where the E_{DEG} is the energy output hourly from DPP (Wh), P_{DEG} is a rate of power output (watts), η_{DEG} is the diesel generator efficiency (%).

4.4.1.3. Modeling of Converter

A converter contains only an inverter For the purpose of converting DC electricity from the PV energy generator into AC electricity, the PV energy generator is connected to an inverter. for purpose of grid interconnection and powering the loads.

$$E_{PVG-IN}(t) = E_{PVG}(t) X \eta_{INV} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. (4.3)$$

The hourly energy output from an inverter is measured in kWh, and the hourly energy output of a PV generator is measured in $E_{PVG}(t)$. Inverter efficiency is measured by η_{INV}.

4.4.2. Energy Systems' Economic and Environmental Costs

4.4.2.1. The Annualized Cost of a Component.

The annualized cost of a component includes annualized capital cost, annualized replacement cost, annual O&M cost, emissions cost, and annual fuel cost (generator). Operation cost is calculated hourly on daily basis.

4.4.2.2. Annualized Capital Cost.

A system component's annualized capital cost is determined by multiplying the initial capital cost in its entirety by the factor of capital recovery. The yearlyized capital cost is determined by:

$$C_{ann,tot} = C_{NPC} X\, CRF_{(i,N)} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (4.4)$$

where CRF(i, N) is the capital recovery factor with the real discount rate of I and the project lifetime of N. CNPC is the total NPC of the project. The cost of energy, or COE, which is the average cost per kWh of useable electrical energy produced by the system and illustrates cost-effectiveness, is yet another important economic criterion for economic analysis. The following equation is used to determine the COE:

$$C_{COE} = \frac{C_{ann,tot},}{E_{served}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (4.5)$$

where E_{served} is the amount of energy used to serve the loads over the year and $C_{ann\ tot}$ is the entire yearly cost.

4.4.2.3. Annualized Replacement Cost

The annualized replacement cost of a system component is the annualized value of all the replacement costs occurring throughout the lifetime of the project minus the salvage value at the end of the project lifetime. Annualized replacement cost is calculated using:

$$C_{arep} = C_{rep}.f_{rep}.SFF(i, R_{comp}) - S.SFF(i, R_{proj}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

f_{rep}, a factor resulting from the possibility that the component lifespan will differ from the lifetime of the project.

4.4.2.4. Annualized Operating Cost

The operating cost is calculated as the annualized value of all costs and revenues, except the initial capital costs.

$$C_{aop} = \sum_{t=1}^{365} \left\{ \sum_{t=1}^{24} [C_{oc}(t) \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

4.4.2.5. Electric production costs (EPC) and levelized cost of energy (LCOE)

The price per unit of electricity is determined by the LCOE (kWh). Includes the initial capital outlay, ongoing operational expenses, fuel costs for the system (if applicable), and discount rates.

$$LCOE = \frac{\sum_{t}^{n} = 1 \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t}^{n} = 1 \frac{E_t}{(1+r)^t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

I_t represents the investment in year t, M_t represents the operating and maintenance costs in a year t, and F_t represents the cost of fuel, E_t represents the energy generated in year , r represents the discount rate, and n represents system's lifespan (years)[34].

CHAPTER 5 RESULTS AND DISCUSSION

5.1. Energy generated and consumed

The presents electricity production for both two generator and PV system to meet the load demand ranging from 14,659kWh to 24,952kWh. As the power plant connected to the grid, when the load demand exceeds the power generated by the plant, the grid intervenes.

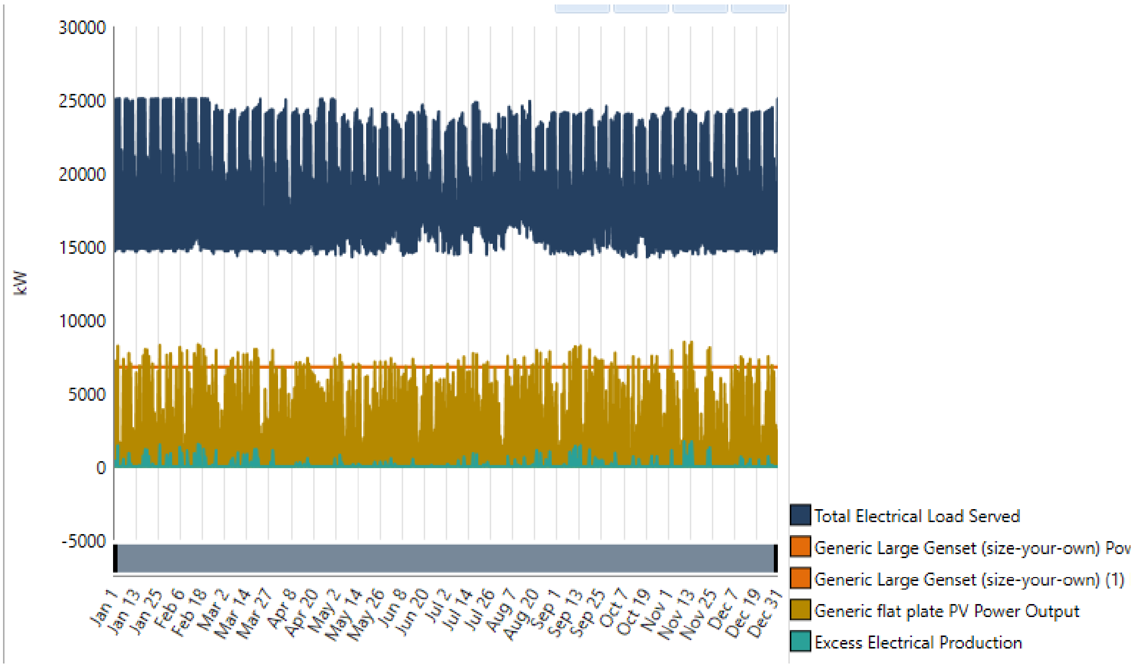

Figure 5.1. Daily energy generation and consumption

5.2. Contribution of Renewable energy

Solar energy was used in the contribution of green energy generation as presented in Figure 5.2 showing that renewable energy contributes 30-40% of the power plant capacity from 9AM up to 3 PM.

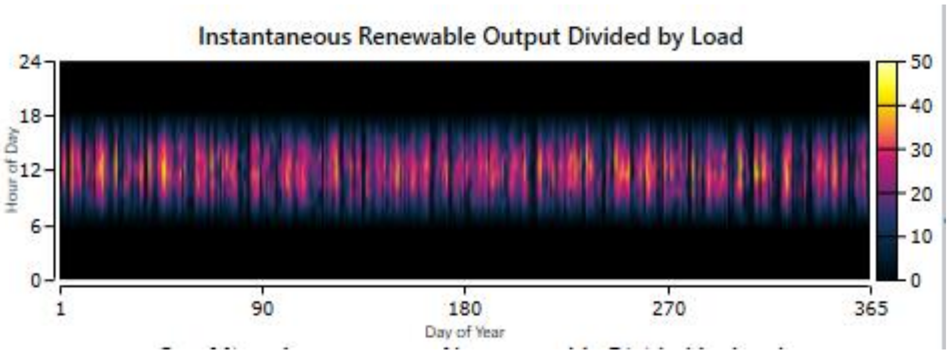

Figure 5.2: Contribution of renewable energy

5.2.1. Power output of PV System

The installed capacity of PV system is 9,000kW to contribute to needed power generation capacity of 20.3MW. The used PV modules have derating factor of 80%, the peak output is 8,511kWp can be generated. The Figure 5.3 shows the daily output power of PV system throughout the year. As it is shown the PV system generate during day time, it produced electricity for 4,380 hours per year and the daily energy production from PV system was 35,158kWh.

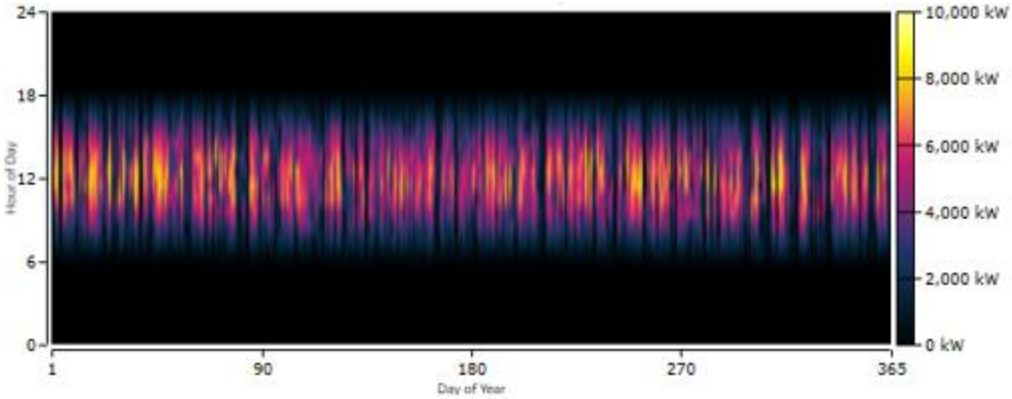

Figure 5.3: PV system output power

5.4. GHG Emissions reduction

The GHG emissions for the PV-diesel hybrid systems connected in Jabana thermal power plant are calculated by using Homer software and are detailed to the Table 0.1 Compared to the dioxide carbon emitted by three diesel generator and PV Diesel generator it was seen that the emissions of dioxide carbon reduce to 46% of the total emission of the three-diesel generator.

Table 5.1: Comparison of GHG Emissions

	Three diesel Generator	**PV-Diesel generator hybrid**
Carbon dioxide kg/year	214,428,448	102,214,349
Carbon monoxide kg/year	456,150	416,979
Unburned Hydrocarbons kg/year	24,210	22,131
Particulate Matter kg/year	3,900	3,566
Sulfur dioxide	366,289	290,732
Nitrogen oxides kg/year	87,424	125,745

5.5. Results from economic analysis

The various significant cost are involved in power generation by PV-Diesel hybrid system. The software was used to optimize the proposed hybrid system designed for cost effectiveness. The cost was calculated by using software with the equation described in chapter 4. The results cost obtained in the table 5.2.

Table5.2: Economic results

Item	Value	Unit
Initial Capital cost($)	165 M	$
COE($/kWh)	0.149	$/kWh
Operating cost($/yr)	23.8M	$/year
Total net present cost($)	150M	$
Total fuel (l/yr)	30,737,088	l/yr
Annual cash inflow	14,225,050	$
Simple payback period	11	Years

Results of the PV-Diesel generator's economic analysis are shown in the Table 5.2 which shows the initial capital cost of 165 M of USD that will be paid within 11 years. There is 11 years of realizing the profit with annual cash flow of 14, 225,050 of USD. One Kwh of energy generated is 0.149$.By comparison the energy cost of power generated by Jabana thermal power plant is very high more than the energy cost of PV-Diesel generator.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

In this research, the contribution of renewable energy in reduction of carbon dioxide. HOMER software was used to design and optimize. Considering the results obtained the following conclusions were taken:

- The proposed D-PV Hybrid system is contribute to the reduction of dioxide carbon about to 47% compared to the dioxide carbon emitted by the diesel generator.
- The suggested pv-Diesel hybrid system is a cost-effective alternative while maintaining the GHG at the lowest level as I stated in the problem description. When compared to the price of Diesel alone, the PV-Diesel generator is less expensive.The Maximum Power generated by PV system 8,511 kW when it works 4380 hours in a year this shows the contribution of 30 to 40% of the total generated of energy.
- For the economic analysis the hybrid PV-Diesel system. The software assumed 25 Years of lifetime and initial capital investment of 165 M of USD that will be paid in the period of 11 years. This shows that the lifetime of the project is greater than to the payback period.

6.2 Recommendation

It is advised that for further study to be done on the hydro-PV hybrid system for the reduction of carbon dioxide instead of using diesel generator and focus on to the cost of dioxide carbon emissions. The results of the analysis recommended that in order to reduce carbon dioxide emissions, electricity from PV systems should be prioritized. PV systems might be used in place of diesel generators.

APPENDICES

APPENDIX A: DAIRLY ENERGY GENERATED BY GENERATOR 1 OF JABANA THERMAL POWER PLANT

Hour	Gen.1 act.energy Gen.1 act.energy SL kWh	Gen.1 act.energy Gen.1 act.energy SL kWh(C)	Gen.1 react.energy Gen.1 react.energy SL kVArh	Gen.1 react.energy Gen.1 react.energy SL kVArh(C)	Gen.1 react.energy imp. Gen.1 react.energy imp. SL kVArh	Gen.1 react.energy imp. Gen.1 react.energy imp. SL kVArh(C)	Gen.1 fuel flow Gen.1 fuel flow SL kg	Gen.1 fuel flow Gen.1 fuel flow SL kg(C)
00-01	6304	4.15E+08	0	97467200	858	17772876	1276	15972948
01-02	6304	4.15E+08	0	97467200	850	17773726	1254	15974202
02-03	6272	4.15E+08	0	97467200	846	17774572	1276	15975478
03-04	6304	4.15E+08	0	97467200	860	17775432	1250	15976728
04-05	6304	4.15E+08	0	97467200	854	17776286	1270	15977998
05-06	6272	4.15E+08	456	97467656	630	17776916	1246	15979244
06-07	6400	4.15E+08	1704	97469360	0	17776916	1294	15980538
07-08	6400	4.15E+08	1344	97470704	0	17776916	1274	15981812
08-09	6400	4.15E+08	1344	97472048	0	17776916	1302	15983114
09-10	6400	4.15E+08	1344	97473392	0	17776916	1280	15984394
10-11	6208	4.15E+08	1312	97474704	0	17776916	1242	15985636
11-12	6208	4.15E+08	1328	97476032	0	17776916	1266	15986902
12-13	6176	4.15E+08	1336	97477368	0	17776916	1266	15988168
13-14	6208	4.15E+08	1336	97478704	0	17776916	1262	15989430
14-15	6208	4.15E+08	1328	97480032	0	17776916	1260	15990690
15-16	6144	4.15E+08	1304	97481336	0	17776916	1250	15991940
16-17	5856	4.15E+08	1240	97482576	0	17776916	1190	15993130
17-18	6304	4.15E+08	656	97483232	0	17776916	1280	15994410
18-19	6304	4.15E+08	328	97483560	0	17776916	1278	15995688
19-20	6272	4.15E+08	312	97483872	0	17776916	1280	15996968

20-21	6304	4.15E+08	312	97484184	0	17776916	1278	15998246
21-22	6304	4.15E+08	272	97484456	0	17776916	1278	15999524
22-23	6304	4.15E+08	264	97484720	0	17776916	1274	16000798
23-24	6304	4.15E+08	256	97484976	0	17776916	1272	16002070
Avg	6269.3	6269.3	740.7	740.7	204.1	204.1	1266.6	1266.6
Min	5856	4.15E+08	0	97467200	0	17772018	1190	15971672
Max	6400	4.15E+08	1704	97484976	860	17776916	1302	16002070
Sum	150464	150464	17776	17776	4898	4898	30398	30398

APPENDIX B: **DAIRLY ENERGY GENERATED BY GENERATOR 2 OF JABANA THERMAL POWER PLANT**

Hour	Gen.2 act.energy Gen.2 act.energy SL kWh	Gen.2 act.energy Gen.2 act.energy SL kWh(C)	Gen.2 react.energy Gen.2 react.energy SL kVArh	Gen.2 react.energy Gen.2 react.energy SL kVArh(C)	Gen.2 react.energy imp. Gen.2 react.energy imp. SL kVArh	Gen.2 react.energy imp. Gen.2 react.energy imp. SL kVArh(C)	Gen.2 fuel flow Gen.2 fuel flow SL kg	Gen.2 fuel flow Gen.2 fuel flow SL kg(C)
00-01	6336	4.07E+08	0	91870528	2524	28430204	1288	14614104
01-02	6496	4.07E+08	0	91870528	2524	28432728	1308	14615412
02-03	6528	4.07E+08	0	91870528	2532	28435260	1328	14616740
03-04	6496	4.07E+08	0	91870528	2470	28437730	1304	14618044
04-05	6528	4.07E+08	0	91870528	2018	28439748	1322	14619366
05-06	6400	4.07E+08	0	91870528	2260	28442008	1284	14620650
06-07	6400	4.07E+08	264	91870792	660	28442668	1306	14621956
07-08	6336	4.07E+08	1440	91872232	36	28442704	1284	14623240
08-09	6400	4.07E+08	504	91872736	48	28442752	1288	14624528
09-10	6304	4.07E+08	896	91873632	0	28442752	1272	14625800
10-11	6208	4.07E+08	472	91874104	46	28442798	1272	14627072
11-12	6144	4.07E+08	0	91874104	798	28443596	1240	14628312
12-13	5984	4.07E+08	240	91874344	330	28443926	1232	14629544
13-14	6016	4.07E+08	32	91874376	626	28444552	1216	14630760
14-15	6016	4.07E+08	200	91874576	232	28444784	1230	14631990
15-16	6048	4.07E+08	80	91874656	264	28445048	1216	14633206
16-17	5856	4.07E+08	8	91874664	1060	28446108	1200	14634406
17-18	6304	4.07E+08	1464	91876128	292	28446400	1270	14635676

18-19	6304	4.07E+08	112	91876240	162	28446562	1296	14636972
19-20	6336	4.07E+08	56	91876296	706	28447268	1278	14638250
20-21	6304	4.07E+08	8	91876304	1026	28448294	1282	14639532
21-22	6304	4.07E+08	8	91876312	834	28449128	1288	14640820
22-23	6304	4.07E+08	176	91876488	402	28449530	1262	14642082
23-24	6304	4.07E+08	288	91876776	230	28449760	1284	14643366
Avg	6277.3	6277.3	260.3	260.3	920	920	1272.9	1272.9
Min	5856	4.07E+08	0	91870528	0	28427680	1200	14612816
Max	6528	4.07E+08	1464	91876776	2532	28449760	1328	14643366
Sum	150656	150656	6248	6248	22080	22080	30550	30550

APPENDIX C: **DAIRLY ENERGY GENERATED BY GENERATOR 3 OF JABANA THERMAL POWER PLANT**

Hour	Gen.3 act.energy Gen.3 act.energy SL kWh	Gen.3 act.energy Gen.3 act.energy SL kWh(C)	Gen.3 react.energy Gen.3 react.energy SL kVArh	Gen.3 react.energy Gen.3 react.energy SL kVArh(C)	Gen.3 react.energy imp. Gen.3 react.energy imp. SL kVArh	Gen.3 react.energy imp. Gen.3 react.energy imp. SL kVArh(C)	Gen.3 fuel flow Gen.3 fuel flow SL kg	Gen.3 fuel flow Gen.3 fuel flow SL kg(C)
00-01	6304	4.01E+08	0	92555104	974	18492632	1306	14356970
01-02	6496	4.01E+08	0	92555104	1020	18493652	1340	14358310
02-03	6496	4.01E+08	0	92555104	1020	18494672	1342	14359652
03-04	6528	4.01E+08	0	92555104	1016	18495688	1338	14360990
04-05	6496	4.01E+08	0	92555104	1012	18496700	1338	14362328
05-06	6400	4.01E+08	448	92555552	752	18497452	1320	14363648
06-07	6400	4.01E+08	1648	92557200	0	18497452	1320	14364968
07-08	6336	4.01E+08	1232	92558432	0	18497452	1308	14366276
08-09	6176	4.01E+08	1224	92559656	0	18497452	1288	14367564
09-10	6208	4.01E+08	1232	92560888	0	18497452	1292	14368856
10-11	6208	4.01E+08	1240	92562128	0	18497452	1294	14370150
11-12	6208	4.01E+08	1256	92563384	0	18497452	1294	14371444
12-13	6208	4.01E+08	1248	92564632	0	18497452	1292	14372736
13-14	6208	4.01E+08	1256	92565888	0	18497452	1290	14374026
14-15	6208	4.01E+08	1224	92567112	0	18497452	1284	14375310
15-16	6208	4.01E+08	1224	92568336	0	18497452	1286	14376596
16-17	5568	4.01E+08	1104	92569440	0	18497452	1168	14377764
17-18	6304	4.01E+08	1264	92570704	0	18497452	1302	14379066
18-19	6304	4.01E+08	1264	92571968	0	18497452	1300	14380366
19-20	6304	4.01E+08	1256	92573224	0	18497452	1302	14381668
20-21	6304	4.01E+08	1248	92574472	0	18497452	1278	14382946

21-22	6304	4.01E+08	1240	92575712	0	18497452	1300	14384246
22-23	6304	4.01E+08	1232	92576944	0	18497452	1296	14385542
23-24	6304	4.01E+08	1240	92578184	0	18497452	1296	14386838
Avg	6282.7	6282.7	961.7	961.7	241.4	241.4	1298.9	1298.9
Min	5568	4.01E+08	0	92555104	0	18491658	1168	14355664
Max	6528	4.01E+08	1648	92578184	1020	18497452	1342	14386838
Sum	150784	150784	23080	23080	5794	5794	31174	31174

REFERENCES

[1] J. Jia, J. Lei, C. Chen, X. Song, and Y. Zhong, "Contribution of renewable energy consumption to CO2 emission mitigation: A comparative analysis from a global geographic perspective," *Sustain.*, vol. 13, no. 7, 2021.

[2] S. NIBEZA, "SUSTAINABLE ENVIRONMENT , A KEY OF SUSTAINABLE DEVELOPMENT 1 . The Concept of Sustainable Environment," *Internatioal J. Res. Econ. Soc. Sci.*, vol. 5, no. 6, pp. 20–36, 2015.

[3] IEA, "Key World Energy Statistics, Paris,.Fransa," 2009.

[4] International Energy Agency, "Key World Energy Statistics 2021," 2021.

[5] Rwanda Energy Group (REG), "ANNUAL REPORT For Rwanda Energy Group, of the Year 2020-2021," 2021.

[6] W. Jun, N. Mughal, P. Kaur, Z. Xing, V. Jain, and P. The Cong, "Achieving green environment targets in the world's top 10 emitter countries: the role of green innovations and renewable electricity production," *Econ. Res. Istraživanja*, vol. 0, no. 0, pp. 1–26, 2022.

[7] Ministry of Infrastructure, "Energy Sector Strategic Plan 2018/19 - 2023/24," *Repub. Rwanda*, no. September, p. 29, 2018.

[8] S. Bimenyimana, G. N. O. Asemota, and L. Li, "The state of the power sector in Rwanda: A progressive sector with ambitious targets," *Front. Energy Res.*, vol. 6, no. July, 2018.

[9] N. Hagumimana *et al.*, "Concentrated Solar Power and Photovoltaic Systems: A New Approach to Boost Sustainable Energy for All (Se4all) in Rwanda," *Int. J. Photoenergy*, vol. 2021, 2021.

[10] T. International, R. Energy, and A. Irena, *BRACING FOR CLIMATE IMPACT : Renewables as a climate change adaptation strategy*. .

[11] L. L. Lou, H. L. Mu, X. Chen, and H. N. Li, "The carbon footprint analysis of thermal power plants," *Adv. Mater. Res.*, vol. 807–809, pp. 814–821, 2013.

[12] S. Kumar, D. Katoria, and D. Sehgal, "Environment Impact Assessment of Thermal Power Plant for Sustainable Development," *Int. J. Environ. Eng. Manag.*, vol. 4, no. 6, pp. 567–572, 2013.

[13] U. Jean De Dieu, A. Teke, and T. Ibrikci, "Current Overview of Renewable Energy Resources in Rwanda," *J. Energy Nat. Resour.*, vol. 5, no. 6, 2016.

[14] M. C. Mukeshimana, Z. Y. Zhao, and J. P. Nshimiyimana, "Evaluating strategies for renewable energy development in Rwanda: An integrated SWOT – ISM analysis," *Renew. Energy*, vol. 176, pp. 402–414, 2021.

[15] J. Mugisha, M. A. Ratemo, B. C. Bunani Keza, and H. Kahveci, "Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia, and Rwanda," *Energy Policy*, vol. 150, no. January, p. 112131, 2021.

[16] H. Gloria, H. Olivier, and I. M. Angella, "Contribution of solar energy for sustainable urban development in rwanda," *Civ. Eng. Archit.*, vol. 7, no. 6, pp. 271–277, 2019.

[17] Rwanda Ministry of Infrastructure, "Ministerial Guidelines on minimum requirements for solar home systems." 2019.

[18] P. J. M. Thomas, P. Sandwell, S. J. Williamson, and P. W. Harper, "A PESTLE analysis of solar home systems in refugee camps in Rwanda," *Renew. Sustain. Energy Rev.*, vol. 143, no. February, p. 110872, 2021.

[19] S. Bimenyimana, G. N. O. Asemota, J. D. D. Niyonteze, C. Nsengimana, P. J. Ihirwe, and L. Li, "Photovoltaic solar technologies: Solution to affordable, sustainable, and reliable energy access for all in Rwanda," *Int. J. Photoenergy*, vol. 2019, 2019.

[20] J. Uwibambe, "Design of Photovoltaic System for Rural Electrification in Rwanda," 2017.

[21] JICA, "Republic of Rwanda Data Collection Survey on Development of Urban Transport System in Kigali city," vol. 2, no. August, 2019.

[22] L. J. Garside and J. H. Schilling, "Geothermal Exploration and Development in Nevada.," *Geotherm Resour Cound Conf*, pp. 1–7, 1973.

[23] A. Battistelli, E. Crestaz, and C. Carmona-Moreno, "The African Networks of Centres of Excellence on Water Sciences Phase II (ACE WATER 2): Status of Geothermal Industry in East African Countries," p. 197, 2020.

[24] S. Dfid, DEW Point, "A Rapid Assessment of a National Energy and Low Carbon Path for," no. May, 2009.

[25] S. Asumadu-Sarkodie and P. A. Owusu, “Carbon dioxide emissions, GDP per capita, industrialization and population: An evidence from Rwanda,” *Environ. Eng. Res.*, vol. 22, no. 1, pp. 116–124, 2017.

[26] G. Rohi, O. Ejofodomi, and G. Ofualagba, “Autonomous monitoring, analysis, and countering of air pollution using environmental drones,” *Heliyon*, vol. 6, no. 1, p. e03252, 2020.

[27] M. Ben Jebli, S. Ben Youssef, and I. Ozturk, “The Role of Renewable Energy Consumption and Trade: Environmental Kuznets Curve Analysis for Sub-Saharan Africa Countries,” *African Dev. Rev.*, vol. 27, no. 3, pp. 288–300, 2015.

[28] J. P. Namahoro, Q. Wu, N. Zhou, and S. Xue, “Impact of energy intensity, renewable energy, and economic growth on CO2 emissions: Evidence from Africa across regions and income levels,” *Renew. Sustain. Energy Rev.*, vol. 147, no. January, 2021.

[29] A. O. Acheampong, J. Dzator, and D. A. Savage, “Renewable energy , CO 2 emissions and economic growth in sub-Saharan Africa : Does institutional quality matter ?,” *J. Policy Model.*, 2021.

[30] T. Qi, X. Zhang, V. Karplus, and T. Mit, “The energy and CO 2 emissions impact of renewable energy development in China *,” vol. 68, no. May, pp. 60–69, 2014.

[31] K. A. Mourad, “Master Dissertation Submitted in partial fulfilment of the requirements for the Master Degree in Presented by CHALLENGING ENVIRONMENT : CASE STUDY OF,” pp. 2017–2018, 2018.

[32] M. Usman, M. T. Khan, A. S. Rana, and S. Ali, “Techno-economic analysis of hybrid solar-diesel-grid connected power generation system,” *J. Electr. Syst. Inf. Technol.*, vol. 5, no. 3, pp. 653–662, 2018.

[33] A. S. Aziz *et al.*, “Design and Optimization of a Grid-Connected Solar Energy System : Study in Iraq of RESs with conventional fossil-fuel-based generators produces hy-,” pp. 1–29, 2022.

[34] N. Hiron, N. Busaeri, S. Sutisna, N. Nurmela, and A. Sambas, “Design of hybrid (Pv-diesel) system for tourist island in karimunjawa indonesia,” *Energies*, vol. 14, no. 24, 2021.

[35] V. Anayochukwu Ani, “Design of a Reliable Hybrid (PV / Diesel) Power System

with," *J. Energy*, vol. 2016, 2016.