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UNIVERSITY OF RWANDA

College of Science and Technology

STUDY OF AGRIVOLTAIC SYSTEM TO OPTIMIZE ARABLE LAND USE FOR ENERGY PRODUCTION IN RWANDA

BY

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Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged and it has been passed through the anti-plagiarism system and found to be compliant and this is the approved final version of the Thesis:

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Signed

Date: **12/11/2021**

This thesis has been submitted for examination with the approval of a university supervisor.

Supervisor: Dr. Ernest MAZIMPAKA

Signed:

Date: **12/11/2021**

Dedication

I dedicate this thesis to my mum **UWAMARIYA Laurence** and my brother **NTWARI Herve Patrick** for their prayers and inspiring me in hard work in my academic journey. To my brothers and sisters for their prayers and encouragement, I truly appreciate all your support and send my love to you all. Last but not least, I thank God for everyday blessing.

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I am truly grateful to my parents whose values navigation taught me to well behave in all aspects of life from my childhood to this exciting step.

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List of Abbreviations:

APV: Agro-Photovoltaics

ARES: Autonomous Renewable Energy Systems

AVS: Agrivoltaics

BRALIRWA: Brasserie et Limonaderie du Rwanda

DRC: Democratic Republic of Congo

EDCL: Energy Development Corporation Limited

EDPRS: Economic Development and Poverty Reduction Strategy

EUCL: Energy Utility Corporation Limited

EPD: Energy Private Developers

GDP: Gross Domestic Product

GoR: Government of Rwanda

HOMER: Hybrid Optimization for Electric Renewable

Hysim: Hybrid energy simulation model

INSEL: Integrated Simulation Environment Language

KW: Kilowatt

kWh: Kilowatt-hour

LER: Land Equivalent Ration

MININFRA: Ministry of Infrastructure

MW: Megawatt

MWh: Megawatt-hour

PV: Photo-voltaic

RAPSIM: Remote Area Power Simulator

RE: Renewable Energy

REG: Rwanda Energy Group

RURA: Rwanda Utility and Regulatory Authority

SOMES: Simulation and Optimization Model for Renewable Energy Systems

SSIT: Small-Scale Irrigation Technology

Wp: Watt-peak

ABSTRACT

Rwanda is a small mountainous country, one of the most densely populated countries in the world, population growth has led to a pressure on food security and land use, over the past 10 years there has been a decline in agricultural land, which has been significantly replaced by housing. High mountains that make up a large part of the country makes electricity expansion very expansive. The most common energy sources in Rwanda are fuel wood biomass, most rural areas in Rwanda do not access electricity from national grid. The purpose of this study is to investigate the feasibility of agrivoltaic system to address the issue of food and energy shortage and optimize land use, a rural area in Nyanza district, Gahondo village located at -2.3690 latitude and 29,7714 longitude was taken as a case study to analyze the feasibility of the system based on the fact that this district was found to have high solar radiation in Rwanda. The performance of the system was analyzed using PVsyst software tools.

The solar radiation data used retrieved from meteo data included in the PVsyst software where the horizontal solar radiation of 5.4 kWh / m^2 / day was measured at the selected area in western province.

With the simulation in the PVsyst of an off-grid solar plant, consisting of 2907 solar panels of 320 Wp per solar panel, and 2 inverters of 420kWac rated power unit, the spacing between the PV rows is 6.4 m were considered where in the simulation this spacing resulted in allow incident radiation of 70% reaching the crop yield, the total power produced by the system was approximately 1419 MWh / year with 85.23% annual performance ratio (PR).

Chapter 1: INTRODUCTION

Renewable energy use is on the rise as the world is increasingly facing environmental degradation as a result of climate change, mostly through human activities that are detrimental to environment, that is why many governments have decided to reduce their carbon footprint, to try fight against the climate change issue and ozone degradation, many agreements has been signed, the most famous was signed in 2016 known as Paris Agreement with the aim of having a stronger response to the danger of climate change. [1]

Solar photovoltaic system is one of the renewable energy technologies that has developed significantly since its inception in the 19th century. The efficiency of solar panels has dramatically increased with drop in price and its technology continues to grow so that no doubt in coming years there will be solar PV systems that are more efficient and cheaper, therefore this technology will continually be used in different aspect of life.

To harvest large amount of electricity, the installation of many solar panels is required and this result in the use of large amount of land, in order to embrace fight against climate change initiative and focuses on the use of renewable energy as clean energy, large solar power plants require large amount of land for efficient electricity production, thus efficient usage of land in Rwanda is essential key in preserving both food and energy security. It is in this context that this study looks at how the same land used in agriculture whether wetland farming or slope farming can be used to produce electricity from solar PV as well.

Rwanda committed in the coming years to have an economy based on technology, industry and fight against climate pollution, so all this will not be possible without first becoming self-sufficient in electrical energy better from renewable and clean source, this study will help to examine the agro photovoltaics or Agrivoltaic systems benefits in producing food and electricity on one plot of land. Investments in renewable energy have increased tenfold in Rwanda in recent years. According to the European Union (EU) GET.invest programme[1]

[1] Rwanda: An initiative to promote the financing of off-grid systems in local currency, Ekah Theodora Onyowoicho on September 7, 2021 at 10:57

1.1 Background

The idea of combining food and energy production on the same land known as agro-photovoltaic or agrivoltaic began to be considered in the early 1980s. Adolf Goetz Berger was among the first to propose the system of using land remains between PV rows for agriculture, the first agrivoltaic was tested in 2013, in the region of Montpellier, France the system was made up of solar panels mounted at 4m height inclined at 25^0 angles. Lettuce was cultivated under PV panels, its production and behavior under shade were evaluated, results showed no effect on yield due to lettuce capability of resisting on shadow.

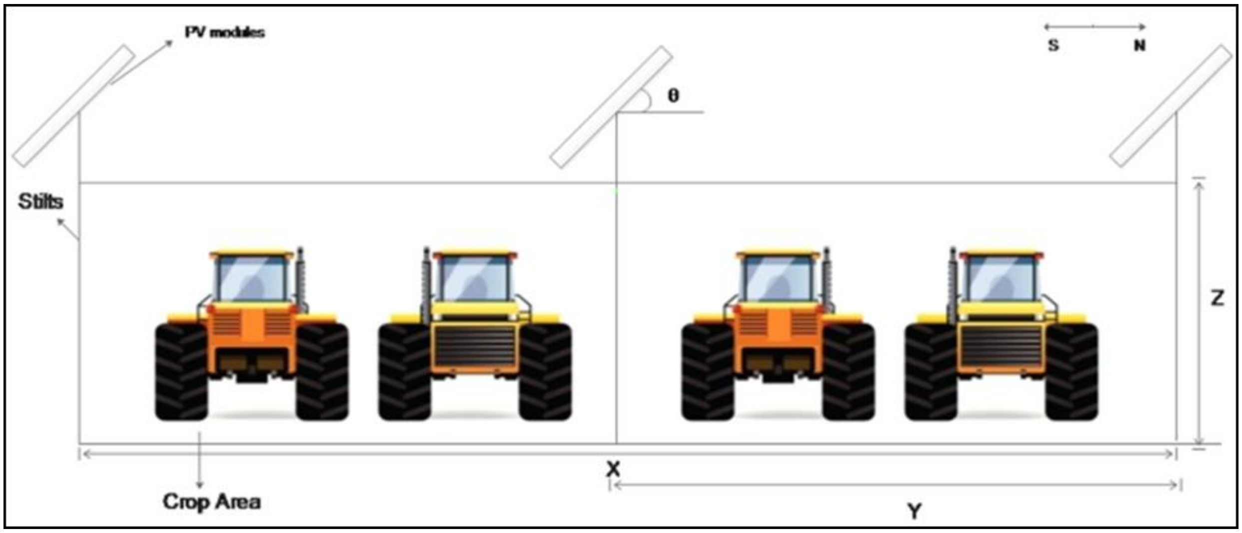


Figure 1: Agrivoltaic farm schematic with PV modules mounted on stilts [2]

In the Agrivoltaic system, to produce maximum output power from solar PV system adjusting tilt angle to tap maximum solar radiation is very essential. The inclined angle, Ɵ, is shown in Figure 1. The optimal inclination angle for the PV module is based on the annual solar radiation. The shade between the PV rows should be reduced, which is generally not a problem in agrivoltaic because the distance between rows (Y in Figure 1) should be larger than the standard solar farm. The power of the PV module depends on the operating temperature of the PV module, due to the ambient temperature, wind speed and solar radiation. However, the introduction of PV into agriculture can also benefit crops. The shade caused by PV modules helps in reducing water evaporation during sunny period and shows very important especially during dry season. It was found that the shadow caused water saving of between 14 and 29% depending on the shadow level.

This benefit can be used extensively in areas with severe droughts, influenced by climate change. The Photovoltaic modules has also been shown to reduce soil erosion and reduce moisture evaporation. Agrivoltaic system can be used to power irrigation and pumping in areas with low electricity or off the grid, to ensure food security.

Finally, the solution of agrivoltaic can also be given as a great solution to the transformation of arable land into photovoltaic farms considering policies that support PV farms which resulting in food production reduction. [2]

1.2 Statement of the Problem

Rwanda is a small landlocked country made up of endless undulating hills and valleys popularly known as ‘the land of a thousand hills', it has a high density population and population growth compared with its neighboring East African countries, The population of Rwanda has increased by 2.4% from 2019 to 2020, an increase of about three hundred and twenty-five thousand people. The fertility rate in Rwanda is 4.10 births per woman [3], despite government efforts related to family planning to reduce fertility rates and slow population growth, increasing in population growth has led to an increase in food prices, energy and promoted an increase in residential land and a decrease in arable land, which has led to an increase in land price, this poses a major investment obstacle in large-scale solar power plant projects, rural electrification programs to provide electricity to rural areas through conventional means like electrical grid extension or diesel generation, are challenged by high cost resulting from remoteness, low level of demand, scattered consumers, low paying capacity of consumers, therefore it is necessary to analyze the potential of agrivoltaic in Rwanda to meet government target of universal access (100%);with on grid connections representing 52% and off-grid 48% especially facilitating in cost effective rural area electrification. [4]

1.3 Objectives

1.3.1 Major objectives

This study examines the concept of combining energy- food nexus on the same land unit as a solution of land use-energy production optimization and investigates farmers and public perceptions on the opportunities to dual land-use systems.

1.3.2 Specific objectives

The major aim of this study would be achieved through the following specific objectives:

- To estimate a surface area of arable land in order to explore the option of combine energy and food production on the same land unit
- To evaluate public perception on the use of agrivoltaic system
- To assess the potential of agrivoltaic system

1.4 Scope of the study

The Study focuses on arable land usage to produce electricity using solar PV system. As shortage of land issue is continually gaining momentum, the scope of the agrivoltaic system in this study centered on how land at rural area level can be used simultaneously for agriculture and electricity generation through solar energy and be used in villages or sent to the grid for additional income.to ensure that the details of the study are sufficient to address the stated goal. This research is designed to have a thorough knowledge of agrivoltaic system and how it can be used to offer a solution to land, food and electricity shortage

1.5 Expected outcomes and significance of the study

1.5.1 Expected outcome of the study

In this study of how the same land used for harvesting crops can be also utilized to produce electricity in Rwanda, the study will evaluate agrivoltaic system to achieve the aim and objective, so after the study of this research the expected outcomes are:

- Efficient land usage, by stepping up utilization of arable land in the way of preserving both energy and food securities.

- Environment conservation benefits as the system results in a reduction of amount of water used in agriculture at a rate of between 20-30%, prevent deforestation, etc.…
- Scaling up farmer’s income by adding revenue made up through PV power, while keeping agriculture.
- Job creation opportunity, apart from farming there will be additional work related to energy generation that will create jobs

1.5.2 Significance of the study

Since the use of energy from solar to generate electricity has reached the business world, sharing information about combination of solar energy generation and crop production on the same piece of land will help farmers and investors in energy sector to explore the potential opportunity for generating income in a complementally and not conflictual way.. This study would have a contribution to the researchers in the fields of energy and agriculture in Rwanda through giving information about the outcomes of using agrivoltaic for food and energy production.

1.6 Organization of the Thesis

This thesis is organized in 4 chapters, Chapter one includes background, problem statement, etc... chapter 2, includes different reviews related to existing works, state of renewable energy sources available in Rwanda, country overview in terms of energy, it discuss also agrivoltaic system, how it works, explanation of main components, chapter 3 discuss about the methods used in collecting data and overview on its analysis chapter 4 gives the results obtained from the simulation and discussion finally chapter 5 makes the conclusion and recommendation through the results obtained.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

Solar energy technologies convert sunlight into electricity through solar thermal technology or photovoltaic (PV) panels, early 20th century marked as the beginning of different studies on solar photovoltaic cell, in the middle of that century through the development in electronic field led to the development of the first solar cell, which was created in 1950's with an efficiency of only 1%, whereas today's solar cell has an efficiency between 18 to 25 percent. Practical research has made great step in the last two decades with the main focus on cheap thin film solar panels as well as organic solar cells have attracted many commercial concerns, a variety of solar panels available today are mostly dominated by single crystal silicon cells. [5]

Early 1981, Adolf Goetz Berger, founder of the Fraunhofer-Institute for Solar Energy Systems ISE, and Armin Zastrow were the first to suggest the use of agrivoltaics (APV). They were trying to address the discussion on food-energy-nexus and suggested a technology to increase output efficiency of PV production and photosynthesis. [6]

Agrivoltaics is a farming concept where the same land is used for solar panels and crops, when this idea first started it seemed impossible due to the fact that the cost photovoltaics panels was high, from the last two decades there have been a tremendous reduction in PV panel price up to 50% and the cost continues to go down alongside the rise in efficiency this has made this forgotten idea turn to be useful as an efficient way of producing food and electricity, a study conducted by Greg A. Barron-Gafford, a professor and researcher at the University of Arizona in the United States in 2019 (Greg A. Barron-Gafford, 2018), proved that this system provides confidence in increasing agricultural productivity and reduce PV panel heat stress, there is also APV-Resola project from the Fraunhofer Institute ISE in Germany proves that the costs of ground-mounted PV systems continue to fall. Experts predict that in about five to eight years, such PV installations will become cost-effective even without the financial support of the governments, many of conducted research show that the agrivoltaics system present many interests. Normally in Rwanda the use of solar energy is on the rise as the government through NST 1, 100% household in 2024 will be able to access the electricity, 48% among them will be connected through Off-grid. [4]. Currently off-grid connection is at 14%; from five years ago there has been an increase of companies investing in solar power generation especially in Rwanda remote rural areas where supplying grid-based electricity is difficult to achieve, sometime investors in power generation do not opt to invest in large solar energy farm due to high land cost in Rwanda.

This innovative idea of agrivoltaics can offer a solution on that issue as well as to the farmland owner by generating addition income from electricity production and even from land lease, in Rwanda over 80% are farmers this make this idea viable in generating income to actors and benefit to the government in terms of water resource management.

2.2 Country outlook: Rwanda

Rwanda is one of the smallest country on the planet earth, it's a landlocked country with total area surface of 26,338 km^2 where 94.7% occupied by land, 5.3 % by water [7] a population of around 12.6 million, it contains 5 provinces North, East, South, West provinces and Kigali city. These provinces were structured in 2006. Prior to the year 2006, provinces were twelve. Currently there are 30 districts. Eastern Province is the largest in area as well as the most populated. [8]. Rwanda shares borders with Burundi in the south, the Democratic Republic of the Congo (DRC) in the west, Tanzania in the east and Uganda in the north. With the support of the International Monetary Fund (IMF) and the World Bank, Rwanda has been able to carry out major economic and structural reforms and maintain economic growth over the past decade, despite Rwanda's natural resources such as hydropower, solar, powder, gas and biomass, the current installed capacity is 235.6 MW from various power plants, especially hydraulics. Only 11% of the available capacity is imported while the rest is domestically generated [8]. Despite the said above economic growth, it has a low per capita electricity consumption (30kWh) compared to Uganda (66 kWh), Kenya (140 kWh) and Tanzania (85 kWh). [9] Moreover, electricity price in Rwanda is about 22.2 % more expensive than the highest in electricity tariff in the EAC [10] government target through NST1 is that by 2024, there would be a hundred percent access to affordable electricity to improve living standards of the populations.

Rwanda plans to achieve 512 MW installed power generation capacity and universal access of

100%, with on grid connections representing 52% and off-grid (especially from solar energy) 48% by 2023/2024

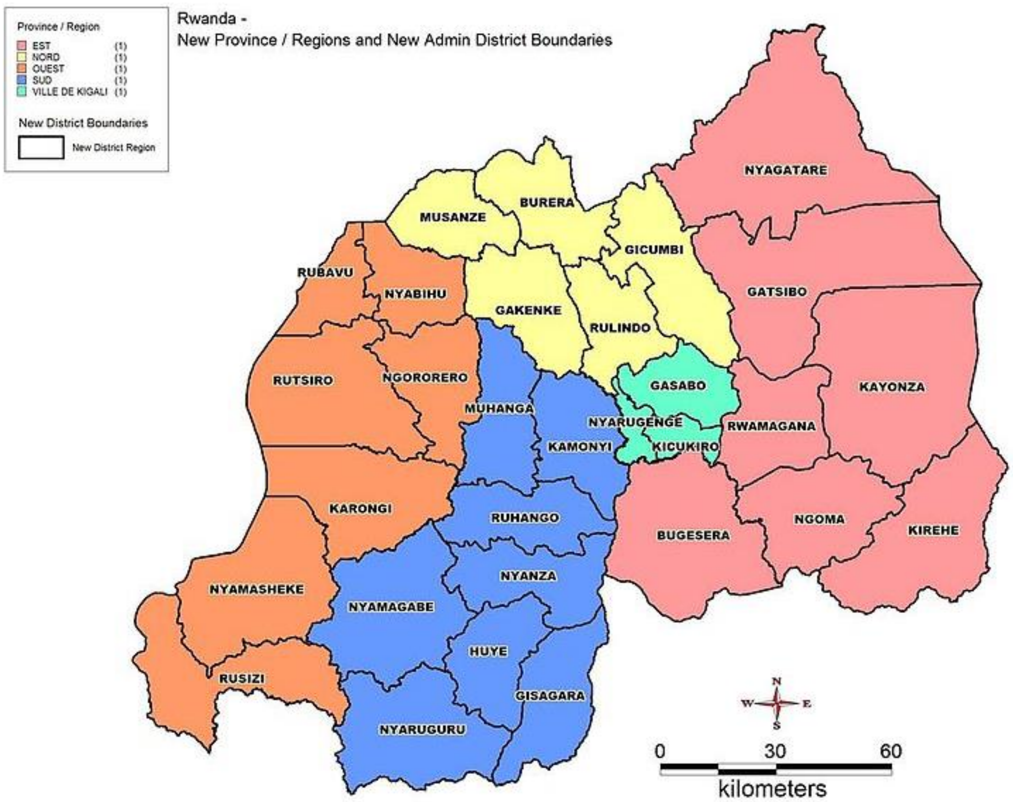


Figure 2: Map of Rwanda (World atlas)

2.3 Structure and Organization of the energy sector

The energy sector in Rwanda consists of 4 parts: biomass, electricity, gas and petroleum. Given the complexity of the sector and its diverse resource base, the mandate of developing the sector is shared across multiple institutions. There is continuous need and efforts to streamline the sector institutional framework to enable integrated resource planning and support improved inter and intra institutional decision-making, avoiding duplication of efforts, the following figure outlines some of the important actors in energy sector [11].

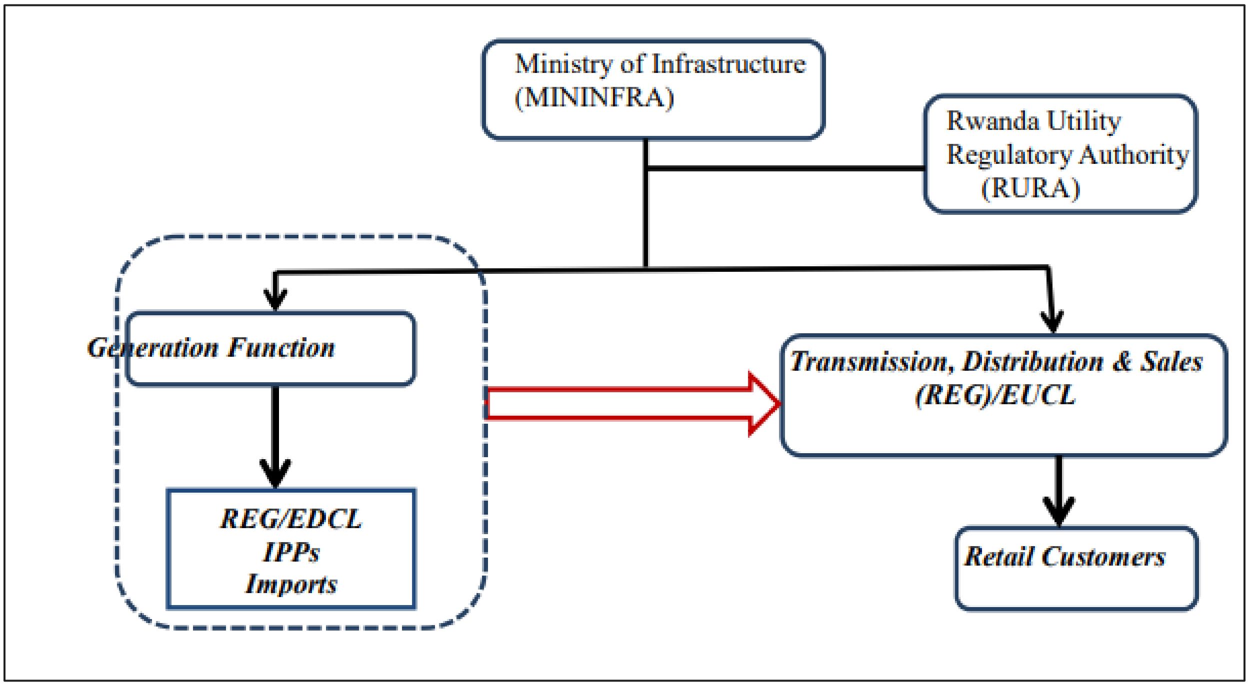


Figure 3: Energy sector structure [11]

The Ministry of Infrastructure (MININFRA) is responsible for policy and strategy development, the monitoring and evaluation of projects and REG (Energy Group in Rwanda) and its sub-branches EUCL (Energy Utility Corporation Limited) and The EUDCL (Energy Development Corporation Limited) are independent bodies with a mandate to change policies and energy programs in the implementation of practical projects to achieve the government's goals in this regard and to improve and maintain the country's electricity distribution system.

Then comes RURA which has the main responsibility of protecting consumers from improper performance when such activities are performed in an efficient, sustainable, and reliable manner. RURA also plays a key role in updating the electricity code, certifying the quality of power services, reviewing and evaluating energy costs, licensing all electricity generation, transmission and distribution firms and petroleum products and storage facilities.

2.4 Energy Resources in Rwanda

Rwanda has a lot of untapped domestic energy resources, source of energy generation include: electricity; geothermal energy; methane gas; electricity; solar energy; wind energy and wastage

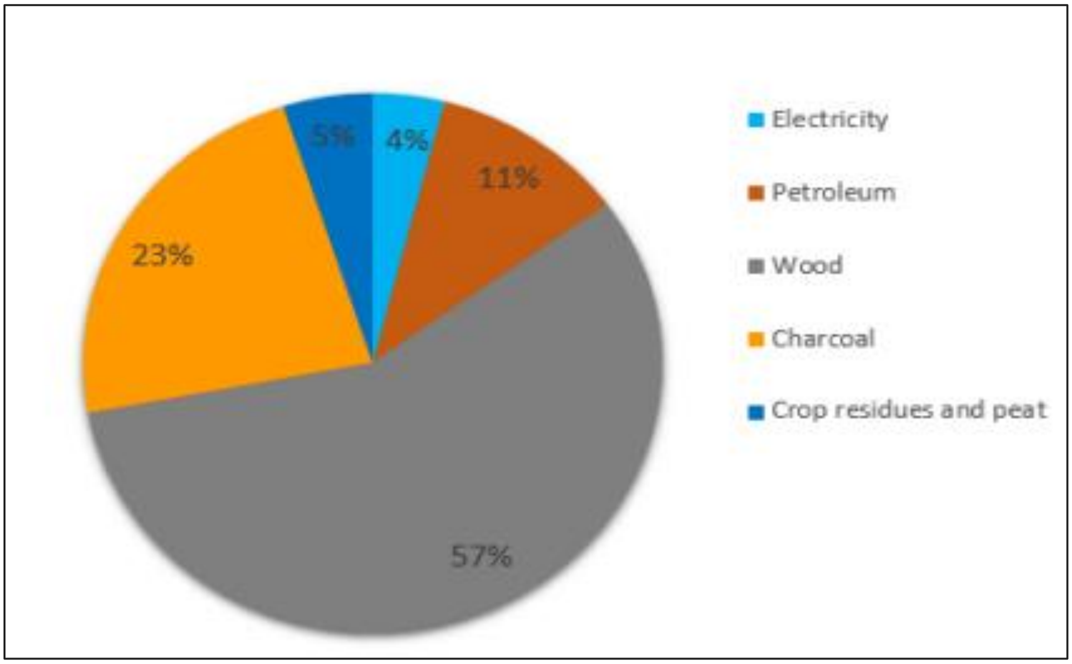


Figure 4: Energy sources in Rwanda [12]

In addition, the presence of a diesel-powered plant in the energy mix means that Rwanda relies on diesel and heavy fuel oil imported from abroad, which leads to the use of foreign exchange reserves to import these fuel oils and this place high demands on Rwanda's foreign exchange reserves and vulnerability to oil price spike this needs to be reduced.

Table 1: List of Power Plants and their capacity in 2020 [8]

OPERATIONAL				
No.	Power plant station	Type	Fuel Type	Capacity
1	Ntaruka	Hydro	Run of river	11.5 MW
2	Mukungwa I	Hydro	Run of river	12 MW
3	Mukungwa II	Hydro	Run of river	2.5 MW
4	Nyabarongo I	Hydro	Run of river	28 MW

5	Rukarara I	Hydro	Run of river	9.5 MW
6	Rukarara II	Hydro	Run of river	2.2 MW
7	Rusizi I	Hydro	Run of river	30 MW
8	Rusizi II	Hydro	Run of river	44 MW
9	Gisenyi	Hydro	Run of river	1.2 MW
10	Gihira	Hydro	Run of river	1.8 MW
11	Murunda	Hydro	Run of river	0.1 MW
12	Rugezi	Hydro	Run of river	2.2 MW
13	Keya	Hydro	Run of river	2.2 MW
14	Nkora	Hydro	Run of river	0.68 MW
15	Cyimbili	Hydro	Run of river	0.3 MW
16	Mazimeru	Hydro	Run of river	0.5 MW
17	Agatobwe	Hydro	Run of river	0.2 MW
18	Janja	Hydro	Run of river	0.2 MW
19	Rushaki	Hydro	Run of river	0.04 MW
20	Mutobo	Hydro	Run of river	0.2 MW
21	Nyabahanga	Hydro	Run of river	0.20 MW
22	Nyamyotsi I	Hydro	Run of river	0.1 MW
23	Nyamyotsi II	Hydro	Run of river	0.1 MW
24	Nyirabuhombohombo	Hydro	Run of river	0.5 MW
25	Nshili I	Hydro	Run of river	0.4 MW
26	Gashashi	Hydro	Run of river	0.2 MW
27	Musarara	Hydro	Run of river	0.438 MW
28	Nyirantaruko	Hydro	Run of river	1.840 MW
29	Giciye I	Hydro	Run of river	4 MW
30	Giciye II	Hydro	Run of river	4 MW
31	Giciye III	Hydro	Run of river	9.8 MW
32	Gaaseke	Hydro	Run of river	0.5 MW
33	Rwaza I - Muko	Hydro	Run of river	2.6 MW
34	Kigasa	Hydro	Run of river	0.272 MW

35	Nyamata Solar	Solar	Solar	0.03 MW
36	Rwamagana Solar	Solar	Solar	8 MW
37	Ngoma Solar	Solar	Solar	2.4 MW
38	Jali Solar	Solar	Solar	0.25 MW
39	Nasho Solar	Solar	Solar	3.3 MW
40	Kivu watt	Thermal	Methane	25 MW
41	Kibuye I	Thermal	Methane	3.5 MW
42	Gishoma	Thermal	Peat	15 MW
43	So Energy LTD (Special Economic Zone)	Thermal	Diesel	10 MW
44	So Energy LTD (Mukungwa)	Thermal	Diesel	10 MW
45	So Energy LTD (Birembo)	Thermal	Diesel	15 MW
46	KP I	Thermal	Diesel	3.6 MW
47	Jabana I	Thermal	Diesel	7.2 MW
48	Jabana II	Thermal	Diesel	21 MW

Table 2: List of Proposed Power Plants projects and their capacity in 2020 [8]

PROPOSED					
No.	Power plant station	Type	Fuel Type	Capacity	Year Completed
1	Rusumo	Hydro	Run of river	80 MW	2021 (expected)
2	Nyabarongo II	Hydro	Run of river	43 MW	2024
3	Rusizi III	Hydro	Run of river	147 MW	2023
4	Rusizi IV	Hydro	Run of river	287 MW	2025
5	Gisagara	Thermal	Peat	80 MW	2021 (expected)
6	Shema	Thermal	Methane	55 MW	2022

The following figure represent energy resources in Rwanda are discussed in order to view the situation of renewable energy in Rwanda, and analysis of potential of renewable energy in Rwanda.

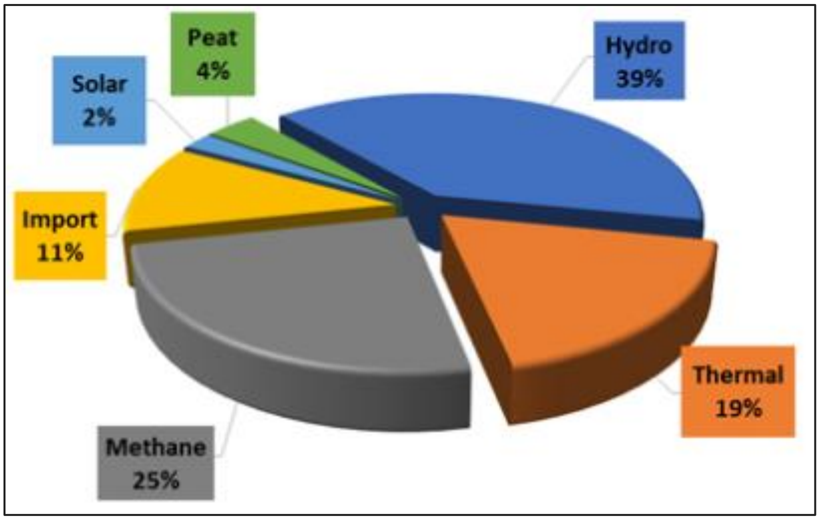


Figure 5: Dispatch energy mix [8]

2.4.1 Hydropower

Since the 1960s, Hydropower has generated a lot of electricity in Rwanda. Rwanda's topography comprises numerous hills and many rivers this present a lot of opportunities for the development of hydropower plants. Current hydro installed capacity makes up approximate 50.5% of the total installed capacity where thirty seven hydropower plants are connected to the national grid and account to 119.44 MW including national and regional shared power plants, therefore electrification through mini/micro hydropower plant (MHPP) is one of the potential to increase generation capacity in Rwanda and boost the rural economy. Rwanda's Hydro Atlas (identified by MININFRA) estimates that there are 333 potential sites for mini and micro hydro-power plants with a capacity of between 50 KW and 1 MW, all together adding up to 12.5 MW that could be electricity supply to rural areas, despite these potential to produce hydropower, the small participation of entrepreneurs in the development and operation of power plants poses a great barrier to hydropower generation as well as other renewable energy. To address this issue government of Rwanda has decided to develop or build these power plants and transfer them to the private sector for operation; this approach is expected to attract investors in this area.

2.4.2 Solar

Rwanda has a good energy potential from solar where average solar radiation is between four to six kWh per square meter per day and approximately 5 hours per day.

Table 3: Rwanda's total on-grid installed solar energy [8]

No.	Solar power station	Installed capacity	Name of the owner
1.	Rwamagana Gigawatt Solar power station	8 MW	Scatec Solar Company & Gigawatt Global
2.	Nasho Solar power station	3.3 MW	Rwanda Energy Group
3.	Jali Solar	0.25 MW	Government of Rwanda
4.	NderaSolar	0.15 MW	Government of Rwanda

The first solar power plant in Rwanda was built in 2008, on top of mount Jali in Kigali city in collaboration with the German province of Rhénanie-Palatinat and the Rwandan government with a capacity of 250 kWp connected to the grid; So far, on grid solar energy is 12,230 MW from five solar PV plants which are Jali solar power plant which produces 0.25MW, Rwamagana Gigawatt, which produces 8.5 MW, Ndera solar power plant which produces 0.15MW and Nasho Solar power plant producing 3.3 MW. [8]

Solar energy has been exploited specially for the following reasons:

- Electrification of rural areas especially schools, clinics, administrative offices, etc.…
- For irrigation in agriculture and
- For heating water used in household replacing electricity and biomass in water heating this has presented a significant cost savings

Figure 6: Crop irrigation under (SSIT) in Ngoma district [13]

The Nasho irrigation project is a project funded by American billionaire and philanthropist Howard G. Buffett, the project consists of an irrigation system that serves 2099 small scale farmers and a solar power plant with a capacity of 3.3 MW which is used in irrigation and connected to the national grid [14], the aim of the project is to increase agricultural productivity and proper use of land and water through the use of all technologies leading to food security among farmers.

Nasho solar power plant surface area can be productive in terms of food production, on figure 7 below, grass underneath the solar panel looks dried up but if there can been a slight increase in height of the solar panel mounting structure alongside use of solar tracking technology this will significantly decrease that drought, which gives hope that the land under the solar panel can also be used to produce food.

Figure 7: Nasho solar power plant

2.4.3 Wind

Rwanda's proximity to the equator, its potential for wind energy is low. A rapid wind power assessment was conducted in five locations in Rwanda in 2011. Wind speed and weather data were analyzed over a period of one year and evidence was found that most of Rwanda is not suitable for wind power. The Eastern Province has been described as one of the most attractive places, and a simple analysis comparing wind and solar energy shows that wind power can compete in the region. However, possible research and evaluation are needed to make this clear.

Another study conducted using an analysis of the wind and power density measurements at the Rwanda meteo Stations showed that the electrical power production at Gisenyi station could be possible with a positive power density and wind speed, while in areas such as Butare, Kigali, and Kamembe, wind power is sufficient only for water pumping or windmills, thus wind resource is not competitive at all, feasibility and detailed assessment research are needed to Identify Wind

Power for commercial use in Rwanda. [15],

2.4.4 Geothermal

Geothermal energy or the heat that comes from the sub-surface of the earth, it is contained in the rocks and fluids beneath the earth's crust, to produce power from this energy, wells are dug a mile deep into underground reservoir to get access to the stream and hot water, and this steam is then used to drive a turbines which are connected to electricity generators, this energy can produce electricity four times cheaper compared to the cost of diesel generated electricity, in 2006 serious investigation, aimed at viewing of geothermal energy sources for electricity generation, undertaken noted that there are four geothermal potential namely Kinigi, Gisenyi, Karisimbi and Bugarama.

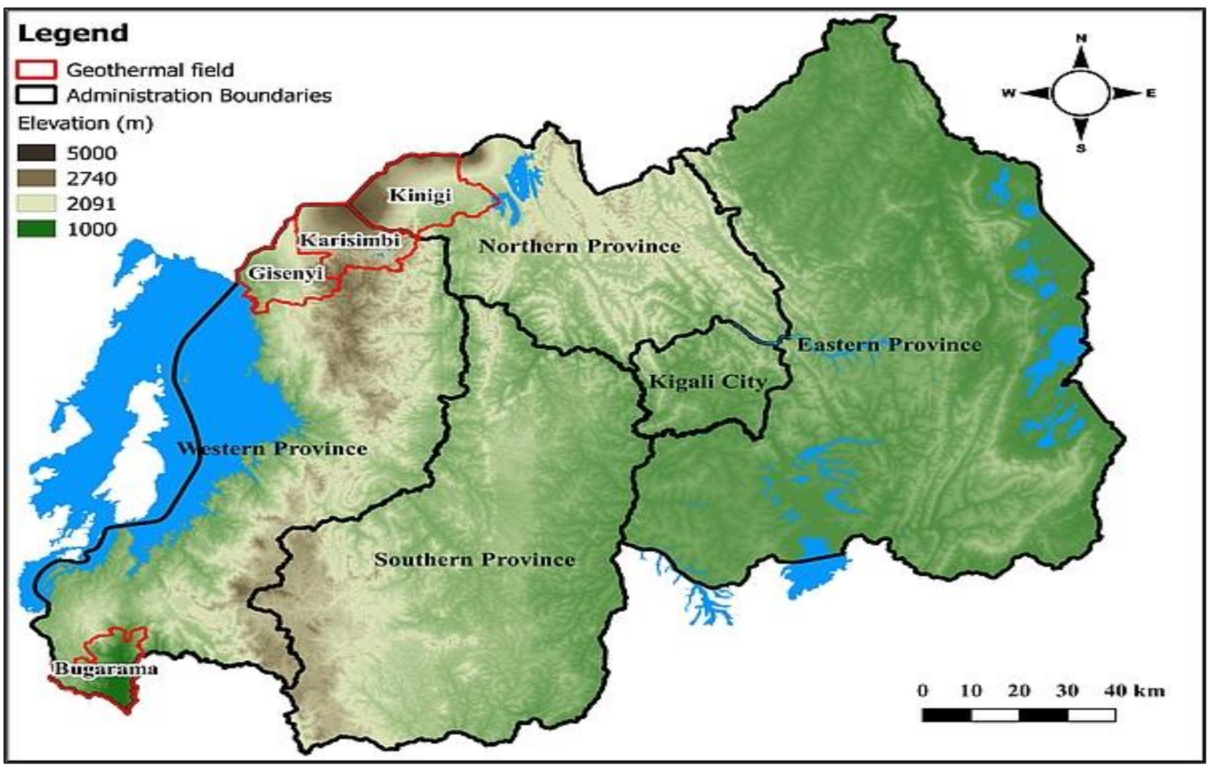


Figure 8: Geothermal potential areas (source: REG, 2018)

A master plan of geothermal energy source was developed in 2015 there is an estimated potential of approx. 100 MW of geothermal power. [8] Currently the plan to explore geothermal is to conduct additional studies in Bugarama and Gisenyi prospect, due to geothermal power commercial viability complexity, the Government is committed in wells drilling exploration to ensure geothermal resource existence in order to reduce risks associated with geothermal exploration.

2.4.5 Biogas

Biogas is an environmentally-friendly renewable energy source from the breakdown of organic matter such as food scraps and animal waste.

The biogas market in Rwanda is predominantly by rural customers, in an effort to protect the environment and improve people's lives The Rwandan government has made efforts in the distribution of biogas digesters around homes, schools and prisons since 2007 to reduce the use of firewood and charcoal which are the most widely used energy in cooking, since the NDBP (National Domestic Biogas Program) began about 10,200 domestic biogas digesters in households, has been constructed with the aim of reducing wood and charcoal use there are also some alternatives such as LPG (liquefied petroleum gas), pellets and briquettes that can be used in cooking.

Table 4: Biogas Digester under NDBP (Program),

No.	District	No. of Installed Biogas digester	Biogas digester in good condition
1.	Burera	337	42%
2.	Bugesera	323	43%
3.	Gakenke	512	60%
4.	Musanze	433	23%
5.	Rulindo	518	59%
6.	Gicumbi	676	16%
7.	Kicukiro	109	62%

8.	Gasabo	174	75%
9.	Nyarugenge	52	35%
10.	Nyamagabe	435	73%
11.	Nyaruguru	281	29%
12.	Kamonyi	253	37%
13.	Muhanga	321	59%
14.	Ruhango	210	82%
15.	Nyanza	349	69%
16.	Gisagara	583	72%
17.	Huye	329	80%
18.	Ngororero	111	67%
19.	Nyabihu	99	23%
20.	Rubavu	125	20%
21.	Karongi	344	17%
22.	Rusizi	206	38%
23.	Nyamasheke	241	13%
24.	Nyagatare	246	36%
25.	Gatsibo	212	60%
26.	Kirehe	813	10%
27.	Kayonza	540	70%

2.4.6 Methane Gas

Gas Methane resource in Rwanda is found in Lake Kivu in western Rwanda, high concentration is situated at 270 to 500 meters in depth, and 2,400 sq. meter, since 2004 the extraction of the gas was done on a small scale, where the gas was used by boilers are being used in the Bralirwa factory in Rubavu, and since then the Rwandan government has begun to look at how to use the gas to increase the amount of electricity used in the country.

Figure 9: KivuWatt plant - Barge on Lake Kivu (source: countourglobal)

Table 5: Methane-to-Power project (Completed and Ongoing)

Power project name	Capacity in MW	Owner	Year of Operation
Kivu watt project	26 MW	Contour Global (US-based company)	2015
Kibuye Power 1	3.6 MW	Symbion Power	2016
Shema Power Lake Kivu	56 MW	SPLK Ltd	Under construction

2.3.7 Peat

Peat, fuel consisting of spongiform material formed by the partial decomposition of organic material, mainly plant material, in wetlands such as swamps, potholes, peat bogs, fens and heathlands. The development of peat is favored by warm moist climatic. [16] A peat study estimated that there are 155 million tons of dry peat on the surface of 50,000 hectares, seventy seven percent of the reservoirs situated near Nyabarongo and Akanyaru rivers and in the Rwabusoro valley. [17] Studies show that there may be electricity potential of 150 MW from reserved peat.

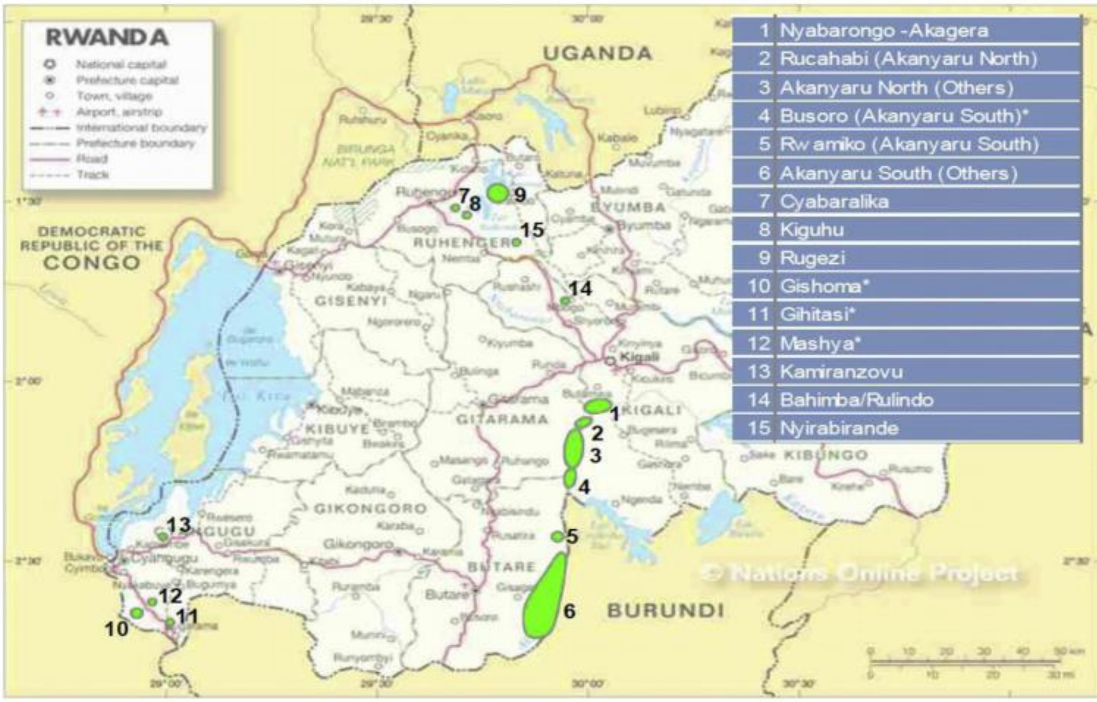


Figure 10: Rwanda Peat distribution map ([18]

The first peat-fired power plant at Gishoma is the first of its kind to be built in Africa, with a capacity of generating 15 MW into the national grid, YUMN Ltd is developing a second peat-fired power plant with a capacity of 80 MW in the Gisagara district, southern province, from February 2017 the project is under construction phase, this plant was constructed under a Build Operate, Own and Transfer (BOOT) basis with a Power Purchase Agreement and a cost of $ 350million upon completion. At the end of the operation period, which is said to be 26 years HAKAN will transfer the power plant back to the Government of Rwanda.

Figure 11: HQ Peat Power plant under construction [19]

Peat power plants have to be constructed near the source of the peat at no more than 15 km, to reduce transportation cost, steam turbine used in these plants are based on CFBC / AFBC (fluidized bed technology) natural circulation, single drum, top supported, water pipelines and semi outdoor design. [18]

2.5 Land use Overview

The country's total area is 26,338 sq. km, with a 24,700 km^2, of land area, 1,250 meters of average altitude. The country's terrain stretches from low-lying plains and swamps in the east to central highlands and rolling hills that meet a mountain range crossing the country from northwest to southeast. The dividing line separating Congo and the Nile drainage system has an average altitude of 2,700 meters and slopes steeply to the west to join Kivu Lake and the valley of the Ruzizi River. 75% of Rwanda's land is used for agriculture; 10% of the total area is permanent land, of which only 0.6% is irrigated. Six percent of the land is wetlands and about nineteen percent of the total area is forested. More than 10 percent of all land is protected. Seventy two percent of the population living in rural areas, population growth is one of the factors that employ pressure on the environment, more people use more natural resources, generate more waste and emit more greenhouse gases, these impacts can be addressed through many responses, including government policies, new technologies and innovation and public motivation for sustainable development. [20]

2.5.1 Agriculture Sector

Agriculture is a main economic activity in Rwanda with seventy percent of the population engaged in the sector and around seventy two percent of the labor force employed in agriculture. The cultivation period can be divided into the first cultivable season (September to January) and the second agricultural season (February to June). In the marshes, where water is plentiful, there is also a third agricultural season for the cultivation of rice and vegetables.

The agricultural sector represents 33% of the national GDP. In general, Rwanda's GDP has grown at a rate of 7% since 2014. In Rwanda, land classified as rural accounts for almost ninety eight percent of the total land area, with about forty nine percent classified as arable. A land law passed in 2005 established a private market for land titles and eliminated the customary tenure system. By law, landowners are required to register their land holdings, and land titles are also available to women and men. However, in some cases, informally married women have precarious land rights and women in general have difficulty claiming inheritance. Tea and coffee are the main exports while plantains, cassava, potatoes, sweet potatoes, maize and beans are the most productive crops. Rwanda exports dry beans, potatoes, maize, rice, cassava flour, maize flour, poultry and live animals to East Africa. [21] Despite remarkable improvements in recent years, the agricultural sector in Rwanda still faces many challenges:

- Land degradation and soil erosion
- Land use and distribution
- High dependence on precipitation and vulnerability to climatic shocks.
- Low levels of productivity for crops and livestock due to low use of inputs, poor production techniques and inefficient farming practices.

2.5.2 Agriculture Land use

Agricultural area includes arable land, land under permanent crops and permanent pasture. Arable land (in hectares) includes land defined by FAO as land devoted to temporary crops (double-cropped areas are counted once), temporary meadows for mowing or grazing, land under market gardens or kitchen gardens and temporarily fallow land. Land abandoned due to shifting cultivation is excluded. Rwanda's agriculture is characterized by small production (the average home land area is 0.33 ha, which indicates a high population density). 8% of the rural population is made up of farmers who mainly use the rain-fed crop because less than 6 percent of the land is irrigated. Rural workers are predominantly women, where 92 % of women are economically active in agriculture.

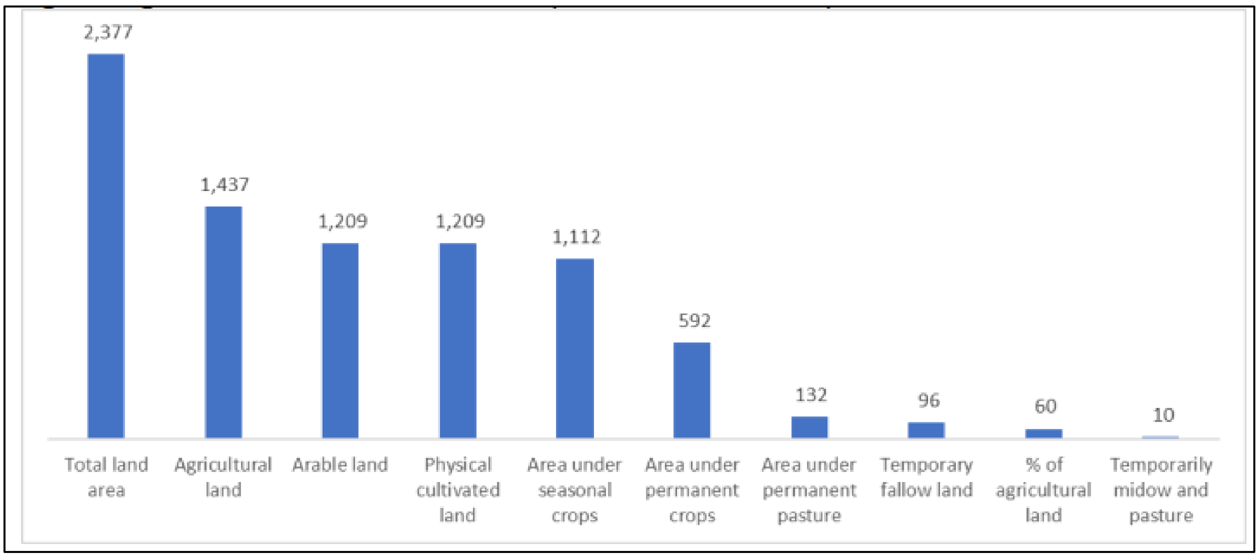


Figure 12: Agricultural land use in season A 2021 (source: NISR, SAS 2021)

According to seasonal agricultural survey season a 2021 report (April 2021) from NISR (National Institute of Statistics) The survey estimates related to cultivated area, production and yield for major crops are summarized as follows:

- Maize: the cultivated area for Maize was estimated at 236,642 ha, this is 7% increase when compared to 2020
- Sweet potato: The cultivated area for sweet potato was estimated at 99,496 ha, an increase of 11% when compared to 2020

- Irish potatoes: The total cultivated area for Irish potatoes was estimated to be 52,196 ha, a slight increase of 1% when compared to 2020
- Cassava: The cultivated area for cassava was estimated at 200,313 ha, an increase of 5% when compared to 2020
- Paddy rice: The cultivated area for paddy rice was estimated to be 15,374 ha, an increase of 5% when compared to 2020
- Banana: The total cultivated area for Banana was estimated at 280,779 ha, an increase of 3% when compared to 2020
- Beans: Beans cultivated area was estimated at 389,149 ha, an increase of 7% compared to 2020

The survey results revealed that 9.2 percent of farmers practiced irrigation, where 8.1 percent of small-scale farmers and 57.3 percent of large-scale farmers were involved. Traditional irrigation techniques were applied by 40 percent of farmers. Lakes/stream and underground water were the most used sources of water for irrigation with 53.7 percent and 25.6 percent respectively.

2.6 Agrivoltaic system

2.6.1 What is Agrivoltaic?

Agrivoltaic or agro photovoltaics is Co-develop the same area for both photovoltaic solar energy and agriculture. Agrivoltaics involves combining crops with solar PV panels installed with enough height to allow farm activities such as allowing agriculture machinery to pass underneath.

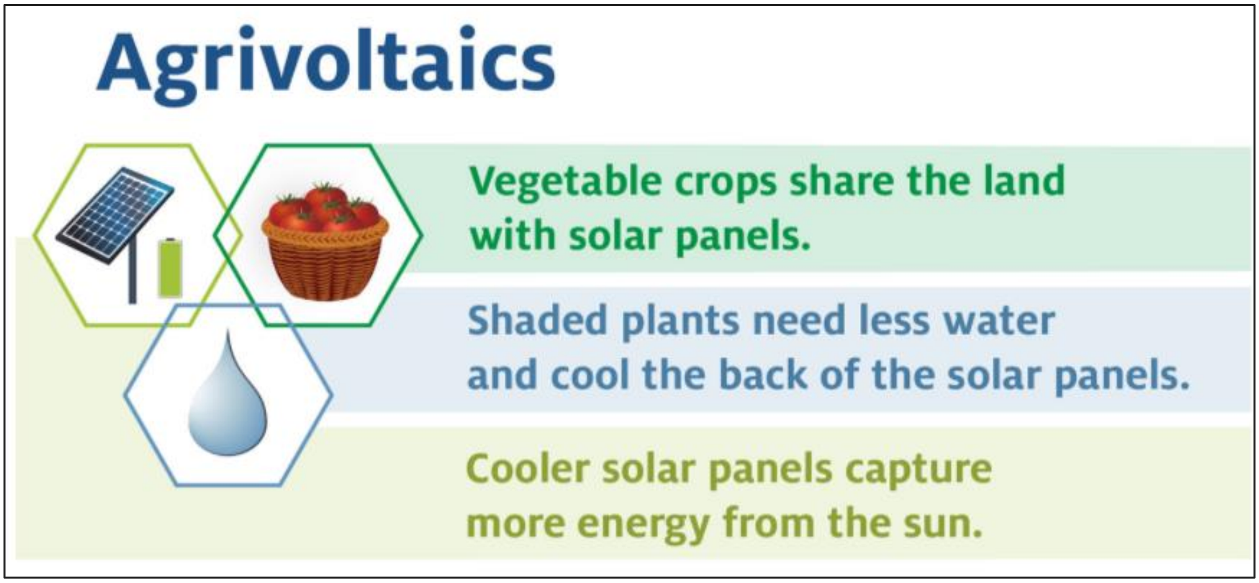


Figure 13: Agrivoltaic in Food-Energy-Water (FEW) Nexus (source: Research Communications, University of Arizona, 2018).

Agrivoltaics delivers eco-friendly solutions:

1. Solar panels protect crops from the worst sun's rays of the midday
2. Solar panel efficiency can be increased due to plants cooler microclimate and, in turn, the panels protect plants from dehydration and sunburn.

In recent years, however, Agrivoltaics concept has become more attractive, as the price of Solar PV equipment has decreased, interest in solar power system has increased, and the pressure between small farmers and solar power producers has increased. Agrivoltaics is seen as a win-win potential. [22]

Experts predict that in about five to eight years, such PV installations will become cost-effective even without the financial support of the governments.

2.6.1 Agrivoltaic system design

In order for the Agrivoltaic system to succeed, the following needs to be taken into account for the efficient use of solar energy in both plants and crops.

- Type of crop (fruits & veggies are known to be suitable)
- Solar panels tilt angle
- Mounting height of the panels
- Solar irradiation
- Climate

2.6.1.1 Fixed solar panels above crops

It is a way to make the installation of a standard solar panels system on greenhouses for agriculture or above the agriculture field, it’s possible to adjust the installation by changing the tilt angle of the panels.

2.6.1.2 Dynamic Agrivoltaic

A simple system built in japan, using lightweight panels mounted on thin pipes not supported by concrete, removable that can be rotated or adjusted when the farmer is cultivating the soil. The space between the panels reduces wind resistance, there are modern agrivoltaic systems that have an automatic tracking system which is beneficial in maximization of electricity and food production. A French company called Agrivolta and Sun'R developed single-axis tracking systems. According to those companies, their system can be adapted to plant’s needs where they use plant growth models, weather forecasting, optimization and software.

2.6.2 Agrivoltaics systems in operation

In recent years agrivoltaic systems have been built in different parts of the world, but most of them are used to examine how agriculture can be connected to solar power installation, these are some of the agrivoltaic systems in operation:

2.6.2.1 Piolenc, France

Sun’ Agri developed an agrivoltaic system on vineyard generating 84kW of electricity in Piolenc, France, which consists of 280 solar panels at a height of 14 feet, the uniqueness to the system is that it uses AI technology to change direction of panels using solar tracking devices.

Figure 14: Poulenc’s experimental Agrivoltaic system. *Image source: Sun ’Agri*

This AI technology can also be used during the season where there is snow or heavy rain by modifying the solar panel tilt angle to protect the crops.

2.6.2.2 Iwaki City, Fukushima, Japan

Figure 15: Solar photovoltaic panels installed above figs, source: Earth Journal

A Japanese farm called agripark Iwaki has an agrivoltaic system on top of a fig tree, in fact the owner wanted that all of his land be converted into a solar power plant, but government regulations prevent it, instead they opt to transform it into agrivoltaic system which consisted of seventy five solar pillars with 25 solar panels each, according to the owner fig tree production has not been affected by the system, which means that the land will continue to produce fig tree alongside electricity from solar panels for daily use..

2.6.3 Importance of Agrivoltaics

Agrivoltaic is the answer to the problems we face as a result of climate change, and the conservation of water resources. In addition to providing electricity for daily use, it can also lead to an increase in agricultural production thus food security and not relying on agricultural seasons, last but not least this system can make a farmer earn additional income through selling of electricity provided the installed solar power system.

It is good to note that not all plants can support agrivoltaic installation, plants that resist to shadow are the one more suitable for the system, it also depend on the location, it is clear that combining agriculture with solar energy is a win-win solution not only for the farmer but also for everyone.

2.6.4 Future of Agrivoltaics

Global investments in solar power generation are increasing very rapidly. Solar power increased its share of global power generation capacity by 50% in 2016 alone, outpacing growth in wind, gas and other renewable technologies. The cost of photovoltaic solar cells, the main investment cost of solar installations using this technology has fallen by 80% since 2008. Agrivoltaics seem generally well suited to market gardening, perhaps less to field crops. The agrivoltaic system also reduces the maintenance problems associated with solar panels closer together and puts the land to productive agricultural use. However, there are still some issues with the cultivation operations to be weighed, such as limiting the size and efficiency of agricultural machinery that can be deployed under and between the frames.

Only time will tell whether agri-photovoltaics will take off in the agricultural industry. Agri-photovoltaics have advantages and disadvantages for farmers. More research and government adjustments to renewable energy discount will promote agricultural photovoltaics to become the mainstream. [23]

Chapter 3: METHODOLOGY

3.1 Introduction

The research involves collecting data which was conducted through an online survey in which participants were from different sectors, especially farmers, and those involved in solar power production, most of whom are members of the EPD (Energy Private Developers) as well as requesting different data at some government institutions including MININFRA (Ministry of Infrastructure) and REG Ltd (Rwanda Energy Group Ltd), this data is known as primary data or first-hand data, then secondary data includes information which already exists most of the time is represented in the form of publications like articles, reports or literature review.

Research design is exploratory especially the collection and analysis of data about the perceptions, of participants aimed at providing information about willingness to use agrivoltaic system for land optimization; the survey was employed to directly engage relevant informants related to Agrivoltaic,

This research method used to address objectives is as follows:

- To explore the option of Agrivoltaic for land optimization
- Collect data through surveys to capture information from relevant sources on their perception of using Agrivoltaic as a means of optimizing land
- Assess the potential of Agrivoltaic in Rwanda

3.2 Data collection

The first-hand data was conducted through a survey which consists of 21 questions in general where four questions are multiple-choice and seventeen with a Likert scale response, most of the participants in the survey were interviewed and their inputs were captured using an online google form, by the help of some of my schoolmates living in different parts of the country, where after interviewing, feedbacks were recorder by filling out an online form often using their mobile phones this strategy has been very helpful in reaching different parts of the country, all of which has been done to adhere to Covid-19 measures that have been put in place such as limiting movements, there was a small number of participants who were interviewed face-to-face and through a mobile phone call, the responses they provided were also filled out to the above said google form by the interviewer,

The aim was to conduct a survey with hundred participants, from mid-July up to the end of August 2021 especially farmers and solar power producers in a different part of the country; the Covid-19 pandemic measures make the expected number unfulfilled, the number of those who were able to successfully complete the survey was 63 which were analyzed with Microsoft Excel.

3.3 Modeling Software: PVsyst

The technical details and major components of the agrivoltaic system have been adequately discussed in the previous chapter 2, According to the problem statement, the main purpose of this study is to see if the agrivoltaic system is the answer to land use and energy production in Rwanda, especially in rural communities where grid extension is expensive to deliver, in this project, there is still a need to harmonize PV production system and crop, all the simulation to examine solar PV production was done using software called PV Syst.

The solar industry's preferred software simulation tool is called Photovoltaic systems (PVsyst) which was developed in 1992 by Andre Mermoud, a Ph.D. physicist at the University of Geneva, as a Windows-based PV simulation software. Mermoud rewrote PVsyst in its entirety in 1999, enabling graphical interface capabilities. [24] It is appropriate for grid-connected, stand-alone, pumping, and DC grid systems and deals with the study, sizing, simulation, and data analysis

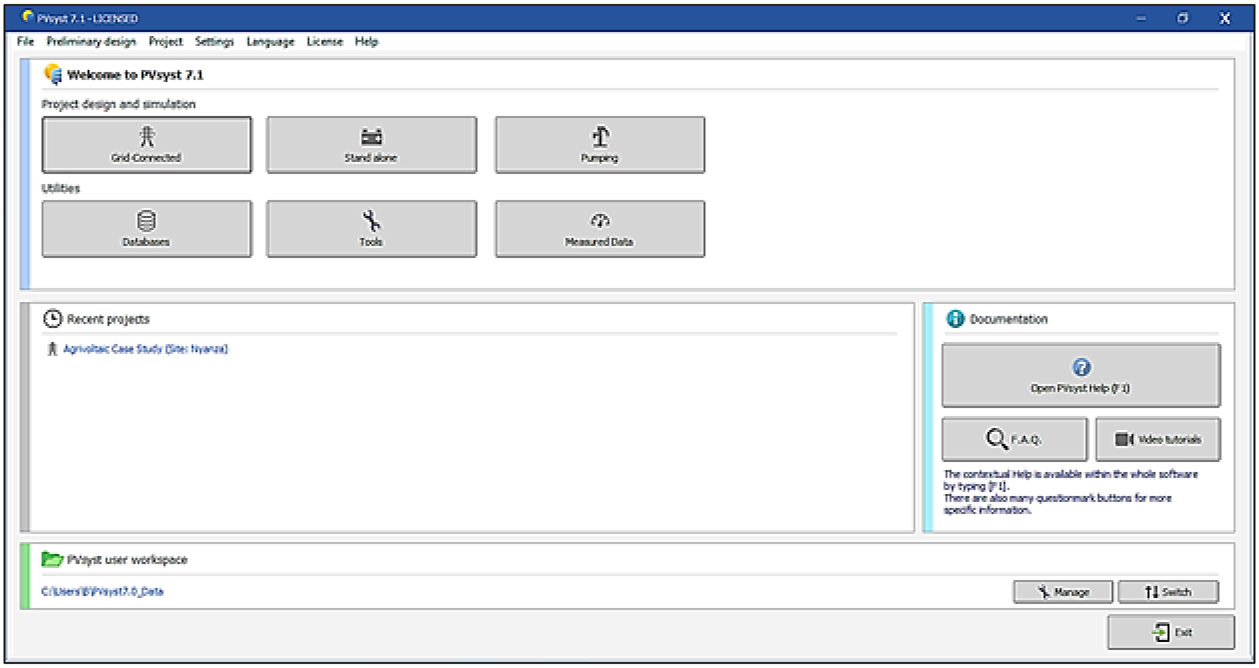


Figure 16: PVsyst: Screenshot

The latest version is PVsyst 7.2 has two components for the user; Project design & simulation and tools (Figure 17), project design & simulation is a simple and fast tool, allowing for the grid, stand-alone, or pumping system pre-sizing. This implements a preliminary economic evaluation and yields the sizes of the components of the PV system, evaluates the monthly production and performance, and enacts a detailed simulation in hourly values, by adding an expert system, to elucidate the PV-field and to select the right components. The tools include the meteo database, with graphs and tables of data and components. PVsyst includes a link to import more than 12,500 PV modules, 4,500 inverters ranging from PNom= 100 W to 2.5 MW, solar pumps, and dozens of batteries. Up to 2009, the PVsyst database was mainly updated using the PHOTON magazine survey, published as printed tables every year. Since this time, the data are provided by the manufacturers themselves.

There are many software tools we can mention such as HOMER, RET Screen, Hysim, HySys, SOMES, SOLSTOR, HYBRIDS, RAPSIM, ARES, and INSEL used for renewable energy study.

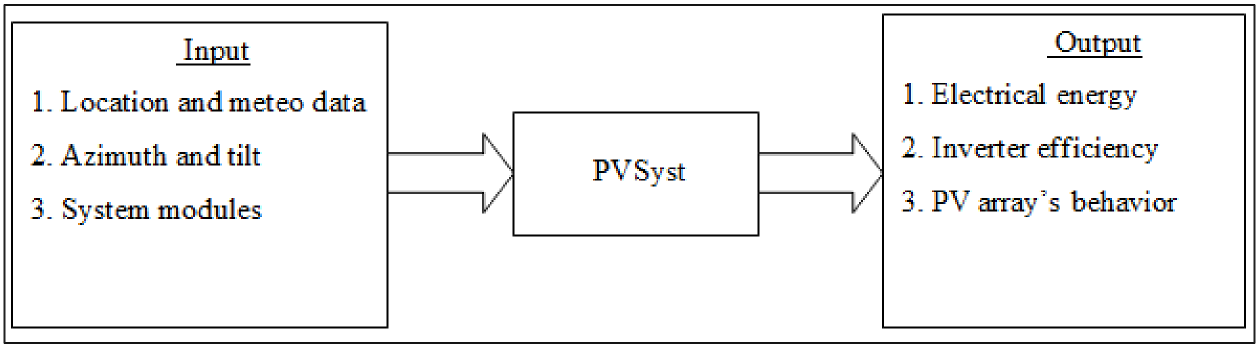


Figure 17: Schematic Representation of PVsyst

3.4 Agrivoltaic system and case study

Upon reviewing different academic papers, there are three application areas that are being actively researched:

- PV + open-field crops
- PV + protected crops (photovoltaic greenhouses)
- PV technology with innovative solutions designed to optimize the light transmission (amount and spectral quality) increasing the compatibility between PV and agriculture. Two scales are distinguished: the system scale (dynamic solutions) and the module scale (enhances light transmittance through PV devices). [25]

In this section, we focus on PV + open-field crops as the most commonly researched area, given that Rwanda is located a few degrees below the equator which makes it a major candidate with a good potential for solar irradiation, which provides more opportunities for solar PV plant development, the following map represents the average electricity production in kWh produced kilowatt of installed PV DC capacity without batteries in Rwanda

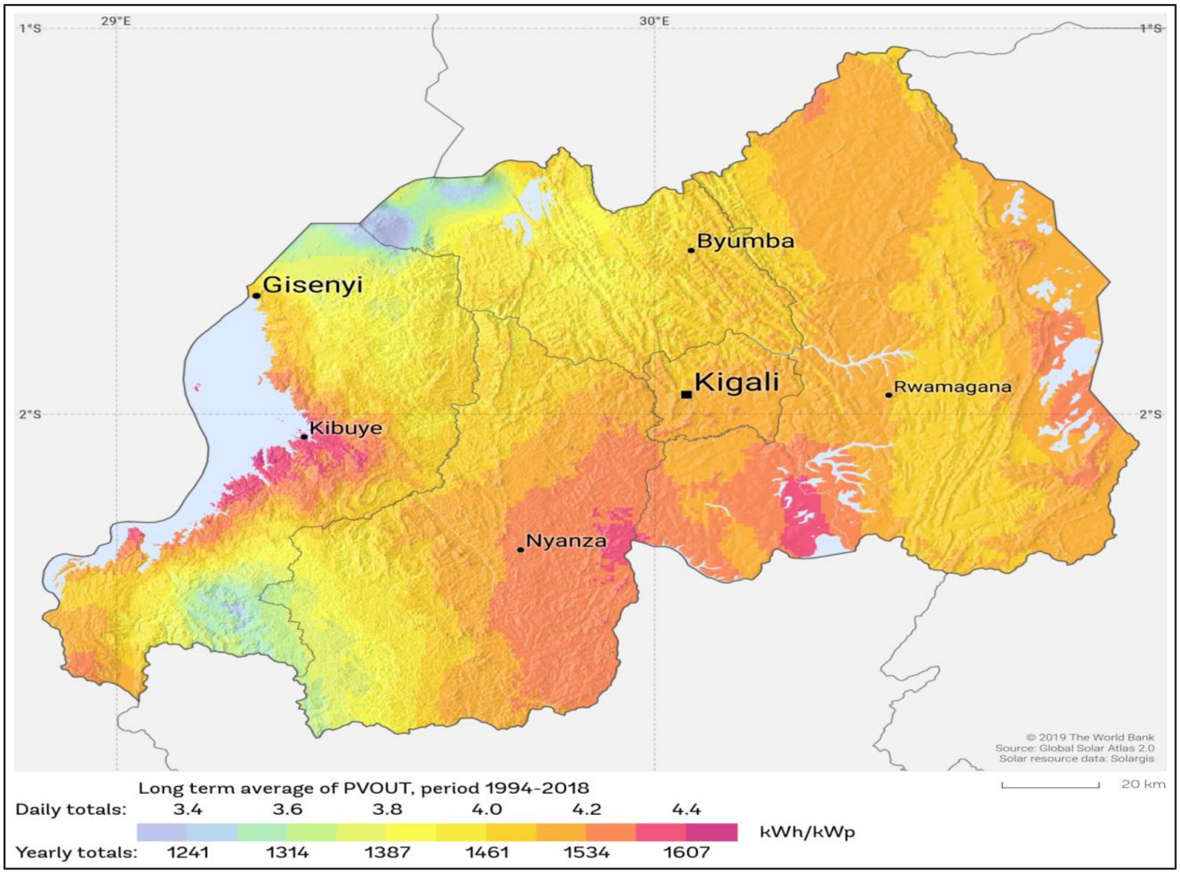


Figure 18: Photovoltaic Power potential in Rwanda (source: Solargis)

There was an exploration of a combined model for agricultural crop yield and PV installations considering land optimization factors.

3.4.1 Solar PV model for Agrivoltaic system Configuration

Solar PV modules in this study are mounted on stilts where space underneath stilts used for agriculture as shown in figure 1, lettuce and cabbage considered to be shade tolerant crop was selected for the area for being planted underneath stilt mounted PV modules.

The program configuration of all components of the designed system and its model is presented in Figure 21, the optimum mounting configuration of PV modules obtained from simulation based on solar irradiation data of case study. Photovoltaic modules Jinkosolar JKM380M-72 were used in the simulation, the stilt configuration used is placed 4m above the ground, with 6.4m spacing between PV arrays rows, having a large space between PV rows such as the one we used in this study results in an average of 70% of incident radiation reaching crop, while the full density of the PV elements, the incident radiation that reaches the plant is about 50%. [2]

3.4.2 Case Study Location Component

Using the existing literature review on agrivoltaic as detailed in chapter two, a solar PV model for agrivoltaic systems has been developed on arable land. Nyanza district was selected for a case study considering its high photovoltaic power potentials (Figure 20). A case study was evaluated for an agrivoltaic system on one hectare of land located in Nyanza (Latitude: -2.3690^0 Long: 94, 5783^0 Altitude of 1722m), PV system output was modeled in PVsyst (version 7.1)

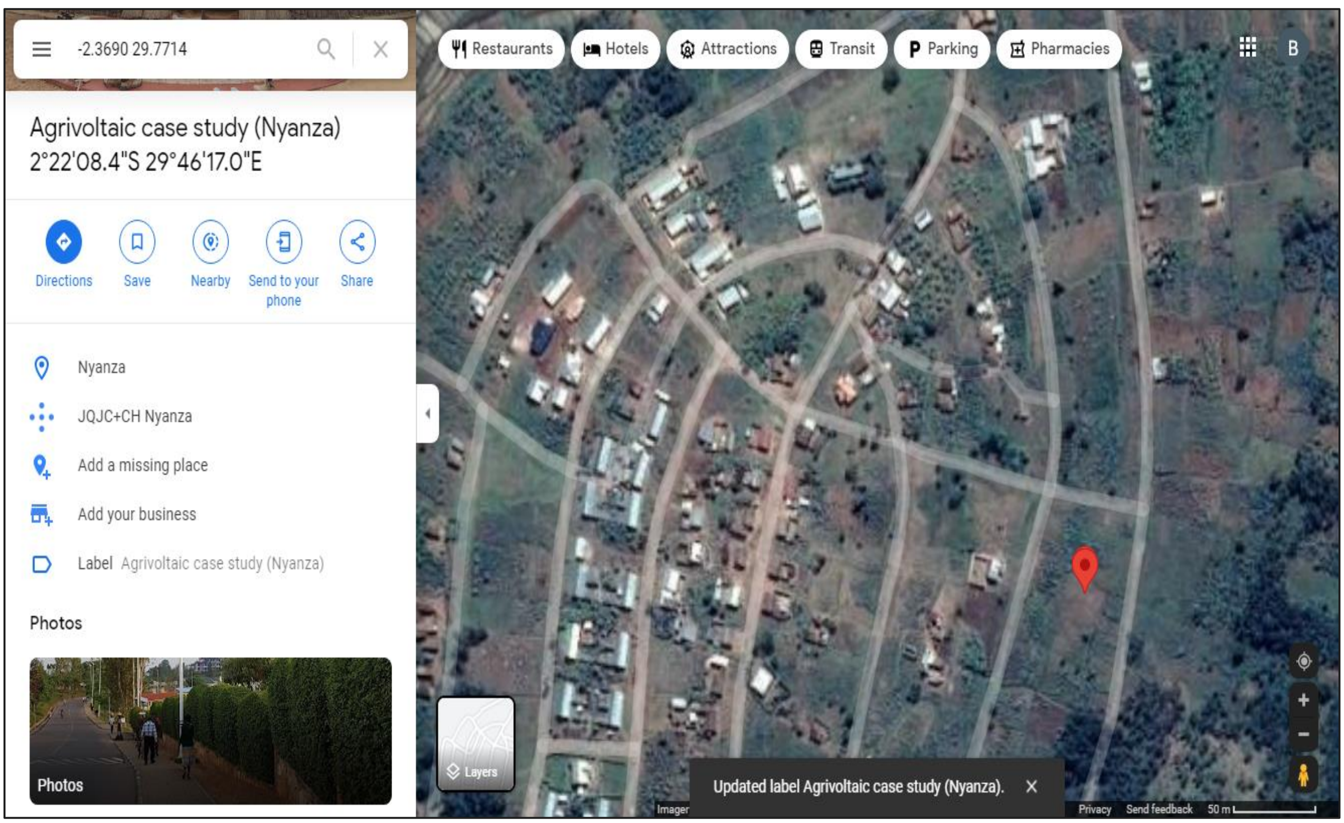


Figure 19: Map of Agrivoltaic case study in Nyanza District (Source: Google map)

3.4.3 Crop Component

In this section we are referring to different research that has been conducted on different crops that are especially resistant to shade, here we can say broccoli, cauliflower, carrots, cabbage, and other shade tolerant crops.

In fact, many veggies can resist partial shading, partial shading refers to areas that are exposed to 3 -6 hours of sunlight in addition to veggies peas and beans are also among the plants that can tolerate partial shading, after reviewing different papers regarding agrivoltaic system, also depending on the case study area we choose for simulation; lettuce and cabbage are good crops for this agrivoltaic configuration as they can withstand shading up to 30%, Lettuce has a growth period of 6–8 weeks and grows up to a height of 15 - 20 cm while Cabbage has a growth period of 80 to 180 days from seed and grows up to a height of 30 - 35 cm. [2]

Chapter 4: RESULTS AND DISCUSSIONS

This chapter discusses the modeling of the Solar PV model for agrivoltaic systems and the results obtained from simulations of the system in PVsyst and also results about the perception of those who successfully complete the survey which was analyzed with Microsoft Excel.

As discussed in chapter 3, the design process of the agrivoltaic system on one hectare of arable land was applied for the evaluation of the efficient land use, with the help of PVsyst version 7.1 and the different obtained results are presented and discussed in this chapter.

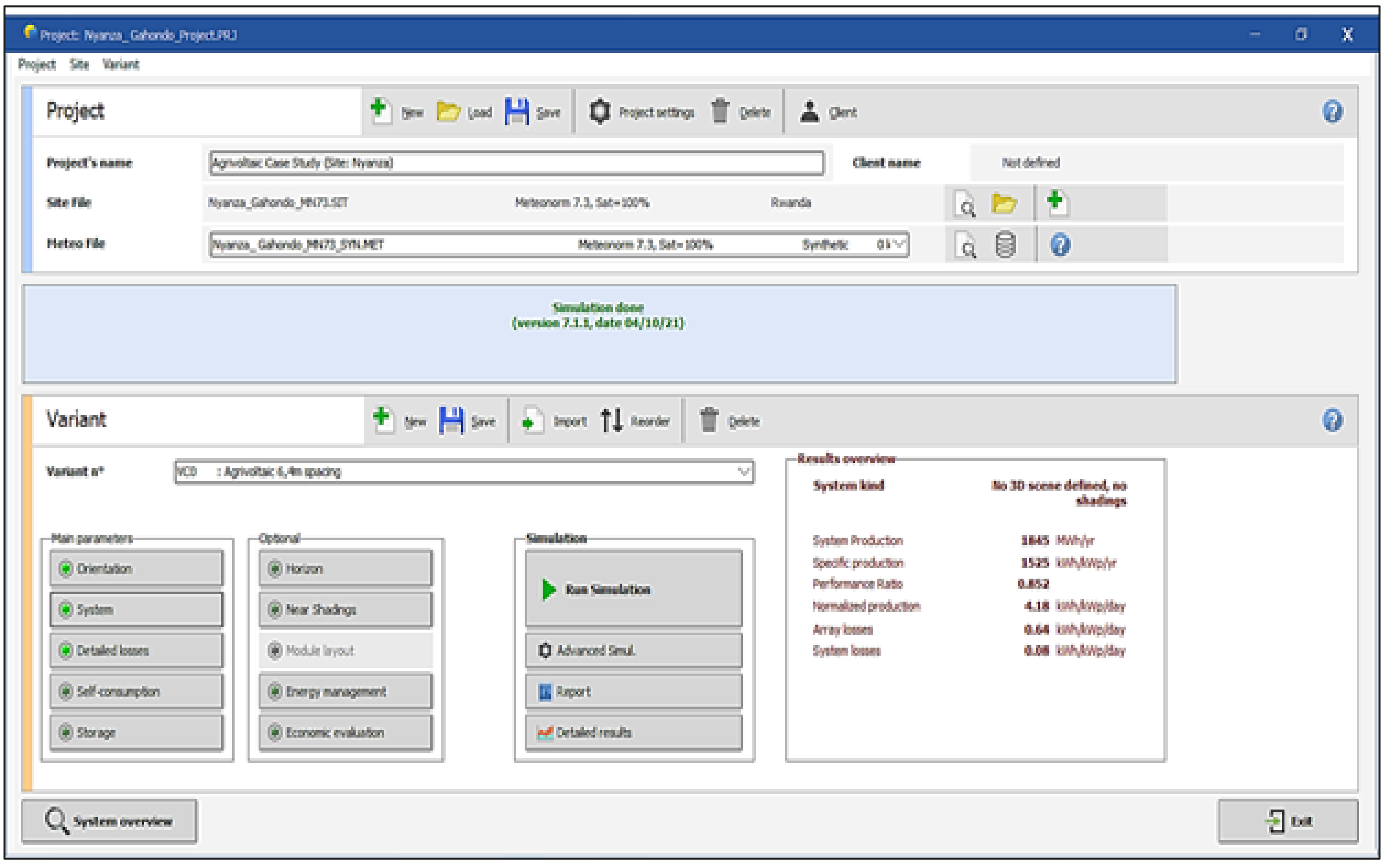


Figure 20: Configuration of the system in PVsyst

4.1 Results

An area of more than 10,000 m^2 has been simulated, with an agrivoltaic system with a spacing of 6.4 m between PV arrays by using Jinko Solar -JKM400M-72 modules on the one-hectare area the system has a tilt angle of 25^o , with a nominal power of 1210 kWp fewer PV rows allows incident radiation of 70% reaching the crop yield.

Figure 21: Satellite image location of Agrivoltaic system case study (source: Google earth)

The above figure 22, shows the possible placement of agrivoltaic system in Nyanza district, located at -2.3690 latitude and 29.7714 longitude, we have chosen to simulate the performance of agrivoltaic system in the field of lettuce or cabbage as some of the most viable crops shade tolerance, these are some of the vegetables that have been proven to be shade-tolerant and adaptive to changing conditions and are suitable for agrivoltaic system implementation. The length of crops is an important parameter in choosing plants for the agrivoltaic system because tall-growing crops can cast a shadow on solar panels, thus reducing electricity generation. In the meantime, plants that are small in size (less than 50cm) and tolerate shade, and use less water are the most common uses in AVS.

4.1.1 Simulation Results

In this AVS case study, the main simulation results were evaluated basing on three key parameters, the first parameter being the total amount of energy produced by AVS with 6.4 spacing between PV arrays on an annual basis known as produced energy estimated in MWh / year, the second parameter is the specific production on an annual basis per installed kWp in kWh / kWp / year. The third parameter is the annual performance ratio (PR) which is 85.23%.

4.1.1.1 Balance and Main results

Table 6: Agrivoltaic system with 6.4m spacing Balance and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	163.4	71.33	21.01	130.9	125.6	137028	134396	0.849
February	142.7	70.02	21.89	123.3	119.1	128977	126544	0.849
March	162.1	74.20	21.87	154.1	150.3	159908	156926	0.842
April	148.5	60.99	20.56	151.5	148.5	157533	154552	0.844
May	152.4	73.44	20.21	165.2	162.4	174619	171341	0.858
June	153.7	60.25	19.14	175.0	172.5	185200	181724	0.858
July	162.4	56.17	18.42	183.6	180.6	193378	189756	0.854
August	158.6	69.21	19.10	167.4	164.2	177294	173957	0.859
September	154.0	65.44	19.73	149.0	145.4	156509	153534	0.852
October	162.1	68.79	20.77	143.6	139.2	150743	147879	0.851
November	148.9	68.81	20.16	122.0	117.1	128542	126051	0.854
December	158.2	74.78	20.85	124.0	118.7	130651	128127	0.854
Year	1867.0	813.44	20.30	1789.5	1743.7	1880381	1844787	0.852

Simulation results from PVsyst of a combined food-energy system with 6.4m spacing between PV arrays generated 1845 MWh per year

The main results are shown in table .., are made of variables such as Global horizontal irradiation, Horizontal diffuse irradiation, Ambient Temperature, Global incident in collector plane with Effective Global irradiance considering soiling losses and shading, in addition to this, DC energy produced by PV array, energy injected into the grid together with losses in electrical equipment, results were obtained in terms of monthly and yearly values and the system efficiency was also calculated.

For our case study location, the annual global irradiance on a horizontal plane is 1867 kWh /m^2, the global incident energy on an annual basis on the collector without optical corrections is 1789.5 kWh /m^2, effective global irradiance after optical loss is 1743.7 kWh / Sq. m, with this sufficient irradiance, the annual DC energy produced from the AVS is 1880.4 MWh and AC energy of 1844.8 MWh which is then sent to the grid.

4.1.1.2 Normalized production

System losses, collection losses, and useful energy produced by installed kWp per day are normalized productions, they were evaluated from the simulation, see below Figure 23; these normalized productions are variables for assessing the PV system performance, where L_c represents Collection losses or PV array capture losses, Ls is the system loss and Y_f the produced useful energy.

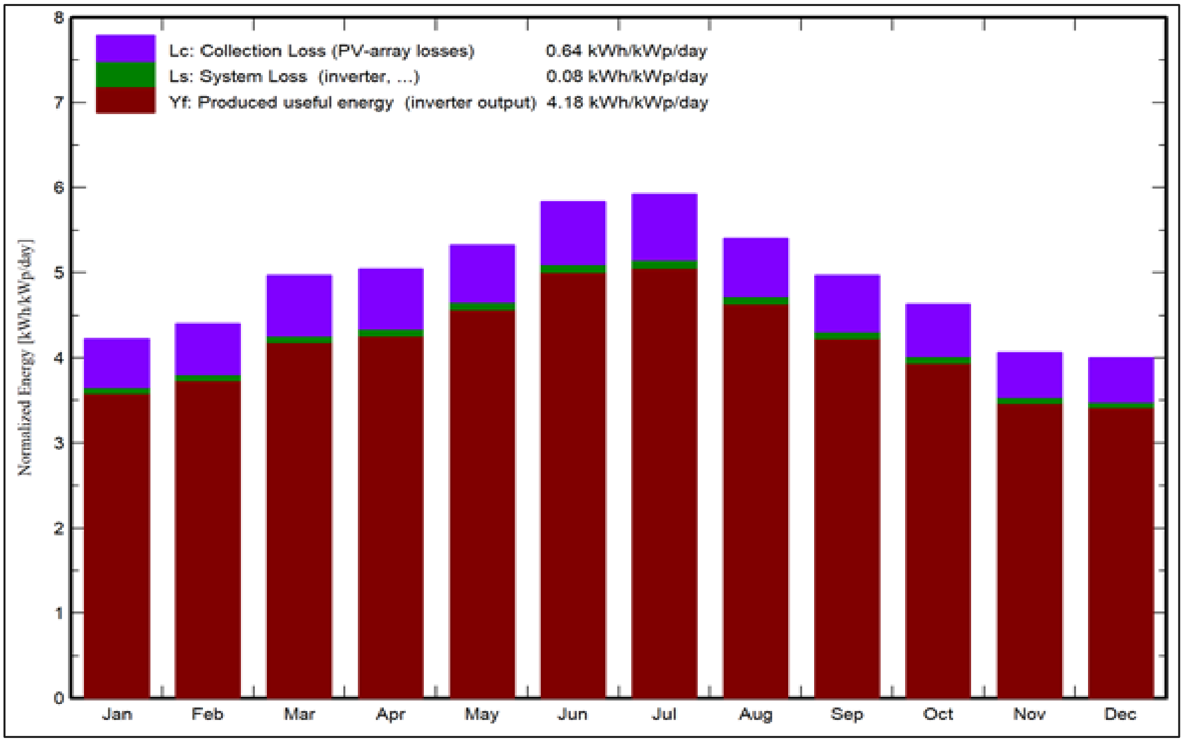


Figure 22: Normalized energy production per installed kWp: Nominal power 1210 kWp

4.1.1.3 Performance Ratio

The performance ratio (PR) for the simulated AVS with 6.4m spacing between PV arrays is 85.23 %, which is considered to be the annual average, as seen in the below Figure 24, there is a slight variation in performance ratio on monthly basis.

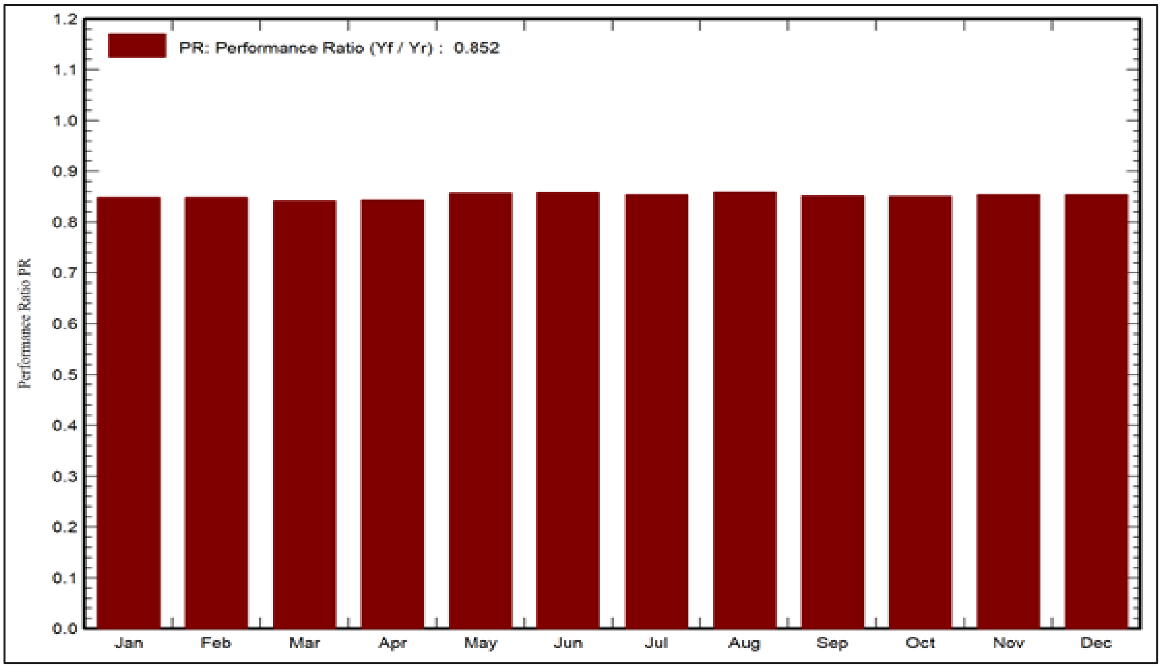


Figure 23: Performance ratio (PR) of AVS

4.1.1.4 Arrow Loss Diagram

The arrow loss diagram obtained from the simulation in the PVsyst software helps us in the analysis of the various losses available during the installation of the PV plant or its constraints to be considered. Below Figure 25 shows the arrow diagram which represents various losses in the system. The total horizontal irradiance is 1867 kWh / Sq. m., the effective irradiance at the collector is 1972 kWh /m^2. This causes energy loss due to the level of irradiance. When this effective irradiance falls on the surface of a PV module or array, electricity is generated. After photovoltaic conversion, the nominal energy under standard test conditions (STC) is 2117 MWh. The efficiency of the photovoltaic generator at STC is 20.24%. The annual virtual energy at MPP is 1880 MWh. The various losses that occur in this stage due to temperature are 8.32%, mismatch loss, modules, and strings are 2.10%, ohmic wiring loss is 1.05%. The energy available annually at the inverter's output installation is 1845 MWh and the same amount is injected into the grid. There are two losses that were possible, Inverter loss during operation (efficiency) amount to 2.2 % and inverter overload loss (Inverter loss over nominal inv. power) that stand at 0.0% in this study.

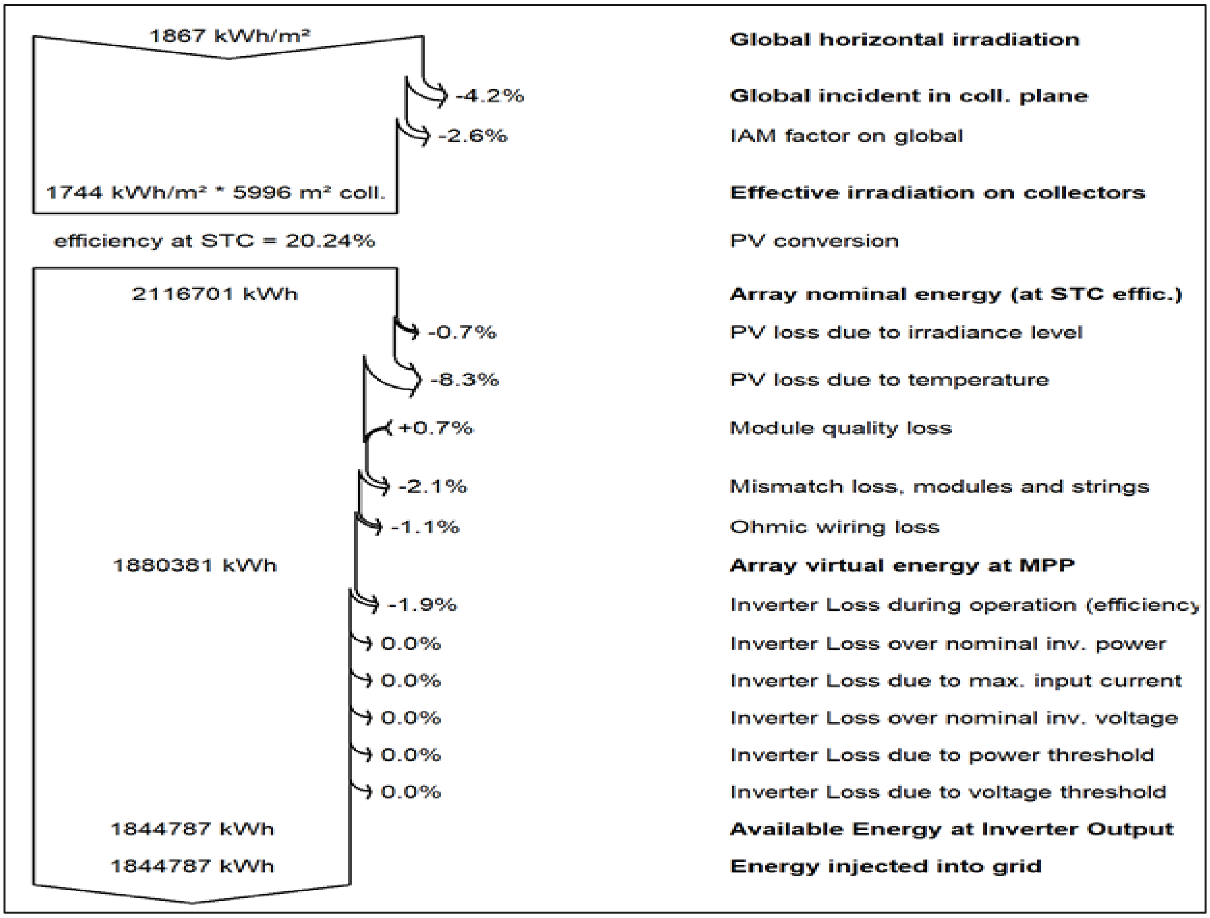


Figure 24: Annual Loss diagram for Agrivoltaic 6.4m spacing

4.1.1.5 Land usage optimization of the AVS

Land Equivalent Ratio is a good approach to optimize the land use for producing both food and energy, an approach like this has been widely used in agroforestry systems where it combines trees and food crops, combining the two has shown the overall productivity of the land

The Agrivoltaic Land Equivalent Ratios (LERs) are benchmarks of the efficient land use utilized to assess the value of combined yields. They make it easier to compare the production of mixtures of food and energy on the same area compared to monocultures. The concept of the Land Equivalent Ratio can be extended to any system that mixes two (or more) types of commodities on the same unit of land, and this concept has been applied to the suggested agrivoltaic systems. [26]

The LER of an agrivoltaic system is defined as:

$$LER = \left(\frac{Y_{Cropin\ AV}}{Y_{Monocrop}}\right) + \left(\frac{Y_{Electricity\ AV}}{Y_{Electricity\ PV}}\right)$$

Where:

- LER=Land Equivalent Ratio,
- AV= Agrivoltaic,
- Y Cropin AV= Yield of the crop in AV,
- Y monocrop= Yield from the conventional agricultural field with full sunlight (kg/m^2).

It is the same for Y electricity AV and Y electricity PV. In this study, we assumed that for the case study of 6.4m spacing between PV arrays the electricity production, the PV mono-system simulation in PVsyst and the production of the system found to be 2813 MWh per year which is considered to be 100% capacity available on an area of one hectare, agrivoltaic system production with 6.4m spacing obtained after the simulation is 1845 MWh per year which is 0.65 c??g 65% of the PV mono-system, on the other hand in terms of crop production in AVS, due to the fact that spacing of 6.4m is large enough to allow 70% incident radiation to reach the crops underneath the solar panels, lettuce as shade-tolerant plant its yield on AVS with a spacing of 6.4m can reach 0.9 [26]

In this study we assumed the relative plant yield to be 0.8, these assumptive values are based on the performed experiments. [2]

Table 7: Land Equivalent ratio of Agrivoltaic system

System	Solar PV Yield	Crop Yield	Total LER
Mono-system	1	1	-
AVS 6.4m spacing	0.65	0.8	1.45

If the LER is greater than 1, the AV system is more effective than the model of separate crops and the PV system, usually integrated systems on the same land tend to have LERs between 1.0 and 1.3, while agroforestry systems have LERs between 1.1 and 1.5 [26], what does it mean an AVS which has an LER of 1.45, this means if you decide to use a mixed system, the yield from 1 ha of the farm would be higher than the yield from 1.4 ha when the systems are separate.

4.1.2 Perception assessment on the use of Agrivoltaic system

This section is about knowing what the public thinks about the Agrivoltaic system in general, the analysis of the views of the participant was done using Microsoft Excel, the questionnaire used in this survey was in the Kinyarwanda language.

It's due to the fact that the key participants in this survey are farmers and most of them in Rwanda do not know widely used languages such as English or French, they use Kinyarwanda very often, but after the survey questionnaire was translated into English in order to interpret the results in the language same as the thesis. In the interpretation of results, the output from participants is highlighted in Figure 26.

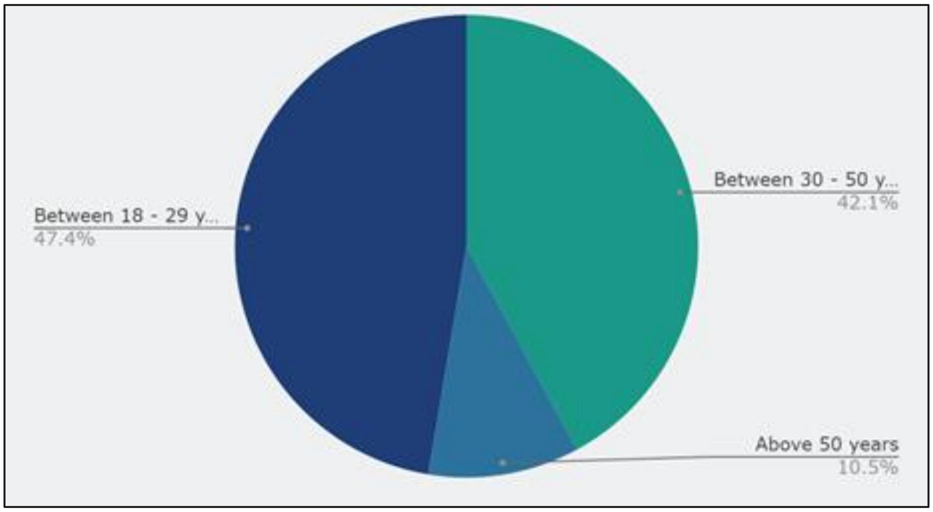


Figure 25: Participants Age level

The majority of participants are between the ages of 18 and 50, it's due to the fact that over half of Rwanda's population are in that age category, and most of them practicing agriculture [27], the smallest number of participants were above 50 years old age group, most of them are no longer able to farm, due to their old age and even in this survey, it was difficult to reach them, because we often reach those we interviewed in the farm field.

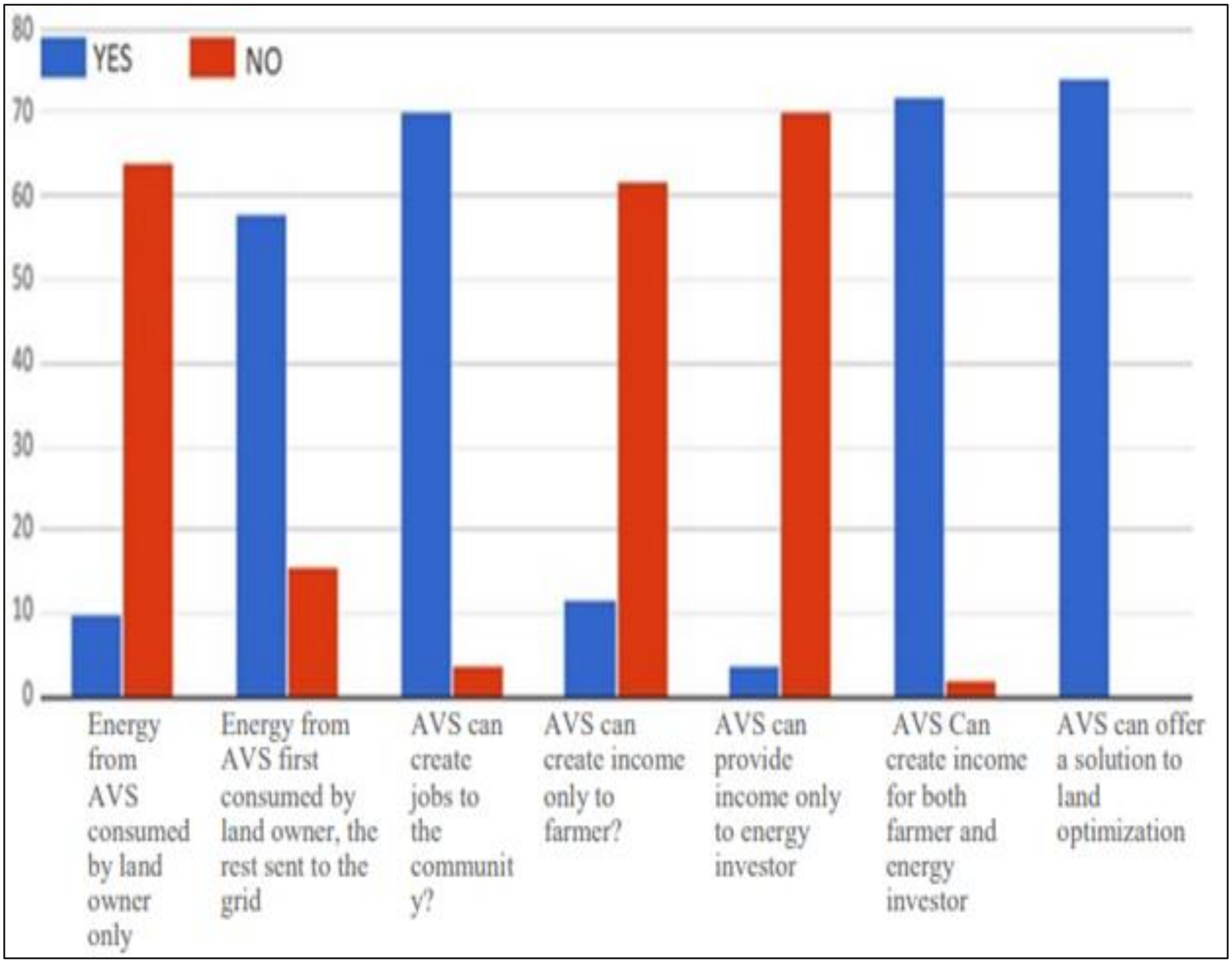


Figure 26: Participants opinion on the implementation of AVS

The survey questionnaire was arranged in a way that demonstrate age level, gender, and different questions aimed at understanding the participants' perception of AVS, through answering questions as shown in Figure 27, the responses consisted of NO or YES, many opposed the idea that the AVS project could involve only the investor or the benefits from using AVS can only be attributed to the investor, they rather support that the AVS project implementation should involve both parties (farm & investor) and the benefits to be distributed fairly.

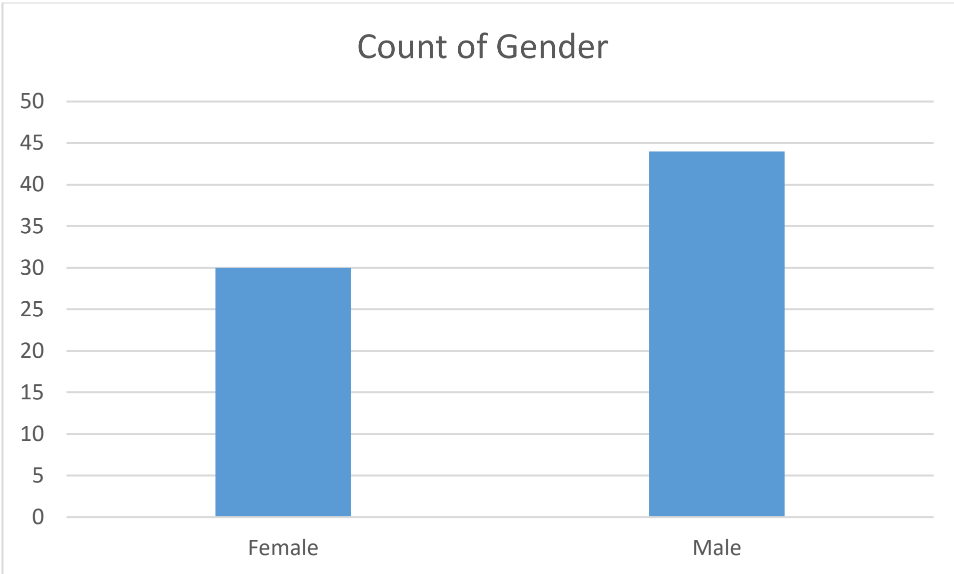


Figure 27: women/men ratio in the survey

4.2 Discussion

This thesis work highlighted the need for a solution for land use, a case study for implementing an agrivoltaic system, where one piece of land is used for solar production and food production, the site considered in our study is located in Nyanza district, southern province, the study demonstrated that the possibilities of combining arable land with electricity generation through PV modules, the average power production of the AVS were analyzed using PVsyst and the results display the potential of the system in optimizing land usage.

Agrivoltaic system increases overall land productivity by more than 50% through the combined use of arable land; the system's case study demonstrates the capability for rural settlements and agriculture in remote areas as a source of off-grid energy. In different studies related to agrivoltaic shows that crops may benefit from PV panels against hail and excess temperature, this may prove AVS importance in the future. From the results, we can conclude that the simulated PV system can provide benefits both to the farmer and installer or investor. In addition, research can be done using a variety of PV technology and appropriate installation to improve performance. The new technology promises to increase food production and reduce water consumption, while also generating energy and extra revenue. Essentially, solar panels are placed on the same soil where crops are grown allowing farmers to reap twice as much sun.

When considering an agrivoltaic system, participants' concerns were that benefits come from using AVS when an investor is involved, there are concerns that a lot of benefits will be attributed to the investor. In addition, there were strong opposing when the government could only be involved in the AVS project, supported by many of the participants is that the AVS project involved the partnership of investors and the farmer otherwise the government becomes a mediator and defender of interests on both sides, various participants highlighted the opportunities that the agrivoltaic system can bring to the farmers.

Chapter 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The thesis work focuses on the exploration of the Agrivoltaic system through case study and the perception of different categories of people includes farmers and those who are in the field of solar energy, all of which are aimed at finding a solution to how the land can be used more efficiently, population growth in Rwanda leads to high demand food, which in turn results in the increase of price food as well as land, an urgent solution is needed to efficiently use the small land we have avoiding the effects of population growth.

Case studies on one hectare of arable land in Nyanza district at the latitude of -2.3690 and latitude of 29.7714 were explored to evaluate the potential of AVS in offering a solution in the efficient use of land, the meteorological data, horizontal solar radiation data in the area were analyzed using PVsyst software, and the results show that AVS potentials to optimize arable land are undoubtedly by exploiting solar energy resources while keeping agriculture.

Providing electricity to rural areas remains a challenging assignment for developing countries. In Rwanda, the cost of electricity is high due to the fact that in many electricity projects, the main source of energy is hydro-power and investing in these projects requires a lot of investment mainly in foreign currency, so in order to take care of inflation, rising costs, shareholders income and take care of their bill, these prices (electricity bills) are likely to get higher and higher, solar panels prices are getting cheaper and prediction is that it will continue to come down, along with an increase in solar PV panels efficiency, which means that as the days go by, investment costs in AVS will decrease and the return on investment period will become shorter.

According to the government's plan that every Rwandan will have access to affordable energy by 2024, the Agrivoltaic system has to be considered as in addition to providing electricity that can be used in rural areas, it has the potential to play an active role in land-use efficiency, water conservation and is also environmentally friendly.

To conclude, AVS is an excellent solution in arable land optimization, food, and energy production, that can make a difference to existing solutions and is very attractive for rural areas electrification, by the involvement of local farmers and locally trained persons for maintaining the system, through government support or non-governmental organizations, the feasibility of the AVS project would be much practical even the cost of electricity would be much lower compared to that from the national grid.

5.2 Recommendations

Given that Rwanda is located just below the equator, renewable energy sources such as solar energy are adequately available in all parts of the country, thus it can be used for electricity generation whether in off-grid or grid systems, using off-grid agrivoltaic systems in rural areas reduces the country access to electricity shortage makes a significant contribution to the optimization of land use and contributes to electricity access. However, implementation of such systems will continue to face challenges such as poverty in rural areas, infrastructure, and insufficient knowledge in using solar energy through insufficiency awareness to use solar energy, and the investor’s risk-taking decision, and other related.

To optimize land use by producing food and energy on the same land, the agrivoltaic system technology has to be promoted and sensitized to improve access to electricity at the national level, agriculture, water, and environmental conservation, the mechanism such as empowering rural communities' income to afford solar PV system can be adopted; the current trend in Rwanda about electricity generation is to build large hydropower plants, large peat-fired power plants and exploitation of methane gas from Lake Kivu to increase country electricity capacity, other renewable energy sources like solar systems can alleviate the country’s electricity shortage and could be cost-effective, therefore government and stakeholders in the energy sector can sensitize investment also in small energy projects specially in distributed renewable generation projects due to its environmental benefits.

References

[1] United Nation, "Paris agreement," 2015.

[2] H. a. P. J. Dinesh, "The potential of Agrivoltaic systems," *Sustainable Energy Review,* vol. 54, pp. 299-308, 2016.

[3] W. P. Review, "Rwanda Population," [Online]. Available: https://worldpopulationreview.com/countries/rwanda-population.

[4] NST1, Rwanda , "7 Years Government Programme: National Strategy for Transformation (NST1) 2017–2024," Government of Rwanda, Kigali, 2017.

[5] A. Stein, "TODAY IN ENERGY," 13 December 2017. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=34112.

[6] A. Goetzberger and A. Zastrow, "On the Coexistence of Solar-Energy Conversion and Plant Cultivation," *Int. J. Solar Energy ,* pp. 55-69, 1982.

[7] W. B. R. 3. Minagri, "ENVIRONMENTAL AND SOCIAL MANAGEMENT FRAMEWORK FOR RSSP 3," Ministry of Agriculture and Animal resources (MINAGRI), Kigali, 2012.

[8] REG, "Generation," 20 September 2021. [Online]. Available: https://www.reg.rw/what-we-do/generation/.

[9] S. B. Godwin N. O. Asemota and Lingling Li, "The State of the Power Sector in Rwanda: A Progressive Sector With Ambitious Targets," *Frontier in Energy Research,* 2018.

[10] S. Bimenyimana and G. N. A. a. L. Li, "The State of the Power Sector in Rwanda: A Progressive Sector With Ambitious Targets," *Frontiers in Energy Research ,* 2018 .

[11] MININFRA, "Rwanda energy policy," Kigali, 2015.

[12] A. T. a. T. I. J. d. D. Uwisengeyimana, "Current overview of Renewable energy resources in Rwanda," *Journal of energy and natural resources, vol. 5,* pp. 92-97, 2016.

[13] J. d. D. NSABIMANA, "Ngoma farmers buoyed by green technology for irrigation," 7 September 2021. [Online]. Available: https://www.newtimes.co.rw/business/ngoma-farmers-buoyed-green-technology-irrigation.

[14] Editorial, "All You Need To Know About Nasho Irrigation Project Inaugurated By President Kagame," KT Press, 11 March 2020. [Online]. Available: https://www.ktpress.rw/2020/03/all-you-need-to-know-about-nasho-irrigation-project-inaugurated-by-president-kagame/. [Accessed 10 October 2021].

[15] U. N. University, "ASSESSING GENERATING CAPACITY OF RWANDA GEOTHERMAL FIELDS FROM GREEN FIELD DATA ONLY," 2009.

[16] O. C. Kopp, "Britannica," 21 November 2018. [Online]. Available: https://www.britannica.com/technology/peat.

[17] D. E. R. O. A. J. D. TheophileMugerwa, "Rwanda peat deposits: An alternative to energy sources," *Energy Reports ,* pp. 1151-1155, 2019.

[18] S.-P. Y. T.-J. K. H.-T. K. Y.-s. j. Y.-c. c. Hakizimana Jean de Dieu K., "Potential for peat-to-power usage in Rwanda and associated implications," *Energy strategy reviews 13-14 (2016) 222-235,* 2016.

[19] D. Sabiiti, "About us: KT Press," 11 July 2021. [Online]. Available: https://www.ktpress.rw/2021/07/rwanda-largest-peat-to-power-plant-delayed-by-covid-19/.

[20] PRB, "Population Reference Bureau," July 2021. [Online]. Available: https://www.prb.org/Publications/Lesson-Plans/HumanPopulation.

[21] FAO in Rwanda, "Food Agriculture Organisation of the United Nations," July 2021. [Online]. Available: http://www.fao.org/rwanda/our-office-in-rwanda/rwanda-at-a-glance/en/.

[22] S. Shemkus, 22 January 2019. [Online]. Available: https://civileats.com/2019/01/22/agrivoltaics-solar-panels-on-farms-could-be-a-win-win/.

[23] N. Technologies, "Agrivoltaics: What is it and how does it work?," 5 December 2019. [Online]. Available: https://nsci.ca/2019/12/05/agrivoltaics-what-is-it-and-how-does-it-work/.

[24] E. Tagliamonte, "pvpros: When to use PVsyst, HelioScope, and SAM," 1 December 2020. [Online]. Available: https://pvpros.com/when-to-use-pvsyst-helioscope-and-sam/.

[25] A. S. Carlos Toledo, "Agrivoltaic Systems Design and Assessment: A Critical Review,and a Descriptive Model towards a Sustainable Landscape Vision (Three-Dimensional Agrivoltaic Patterns)," *Sustainability,* 2021.

[26] D. C., H. Marrou, G. Talbot, L. Dufour, A. Nogier and Y. Ferard, "Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes," *Renewable Energy 36,* pp. 2725-2732, 2010.

[27] W. B. data, "Population, total - Rwanda," 2020. [Online]. Available: https://data.worldbank.org/indicator/SP.POP.TOTL?end=2020&locations=RW&start=1960&view=chart.

[28] WFP, "World food programme," 2021. [Online]. Available: https://www.wfp.org/countries/rwanda.

[29] Umeme, "Tariffs," 2021. [Online]. Available: https://www.umeme.co.ug/tariffs.

[30] M. Trommsdorff, "An Economic Analysis of Agrophotovoltaics: Opportunities, Risks and Strategies towards a More Efficient Land Use," *Constitutional Economics Network Working Paper Series ISSN No. 2193-7214 CEN Paper No. 03-2016,* 2016.

[31] Sun'Agri, "Dynamic Agrivoltaic System," [Online]. Available: https://solarimpulse.com/efficient-solutions/dynamic-agrivoltaic-system#.

[32] C. B. Ruwan Chamara, "Agrivoltaic systems and its potential to optimize agricultural land use for energy production in Sri Lanka: A review," *Journal of Solar Energy Research (JSER),* vol. 5, no. 2, pp. 417-431, 2020.

[33] Rura, "Tariffs," 2020. [Online]. Available: https://rura.rw/index.php?id=204.

[34] P. S. Molina, "When agrivoltaics meet energy communities," 03 March 2021. [Online]. Available: https://www.pv-magazine.com/2021/03/03/when-agrivoltaics-meet-energy-communities/.

[35] Mininfra, "Energy Division," [Online]. Available: https://www.mininfra.gov.rw/digital-transformation-1-1.

[36] Y. K. T. M. Mehreen Gul, "Review on recent trend of solar photovoltaic technology," *sage journals Volume: 34 issue: 4, ,* pp. 485-526, 2016.

[37] P. Magazine, "Agrivoltaics: Where are we heading?," 03 March 2021. [Online]. Available: https://www.pv-magazine.com/magazine-archive/agrivoltaics-where-are-we-heading/.

[38] E. G. Kironde, "Rwanda state of environment and outlook report," Rwanda Environment Management Authority (REMA), Kigali, 2019.

[39] Kenya Power, "Electricity tariffs," 2021. [Online]. Available: https://www.kplc.co.ke/category/view/77/electricity-tariffs.

[40] F. I. f. S. E. S. ISE, "Research Projects/ APV-MaGa," 2020. [Online]. Available: https://www.ise.fraunhofer.de/en/research-projects/apv-maga.html.

[41] M. A. P.-Z. R. L. M. ,. L. F. S. Greg A. Barron-Gafford, "Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands," *Nature sustainability,* 2018.

[42] Ewura, "tariff-electricity," 2021. [Online]. Available: https://www.ewura.go.tz/tariff-electricity/.

[43] M. P. Debaleena Mujamdar, "Dual use of agricultural land: Introducing ‘agrivoltaics’ in Phoenix Metropolitan Statistical Area, USA," *Landscape and Urban Planning ,* 2017.

[44] S. Babits, "The Resurgence of Solar Agriculture," 2019. [Online]. Available: https://www.anthropocenemagazine.org/2018/09/the-resurgence-of-solar-agriculture/.

[45] M. R. A. F. Ahmed Hossam Eldin, "A Review on Photovoltaic Solar Energy Technology and its Efficiency," in *17th International Middle-East Power System Conference (MEPCON'15)* , Mansoura, Egypt, 2015.

[46] R. U. R. A. (RURA), "About RURA," 20 September 2021. [Online]. Available: https://rura.rw/index.php?id=67.

[47] A. d. f. A. d. B. MININFRA, Sustainable Energy for All Rapid Assessment and Gap Analysis, Kigali: Sustainable Energy for All, 2014.

[48] NLUDMP, "National Land use & Development Master Plan 2020 - 2050," Kigali, 2020.

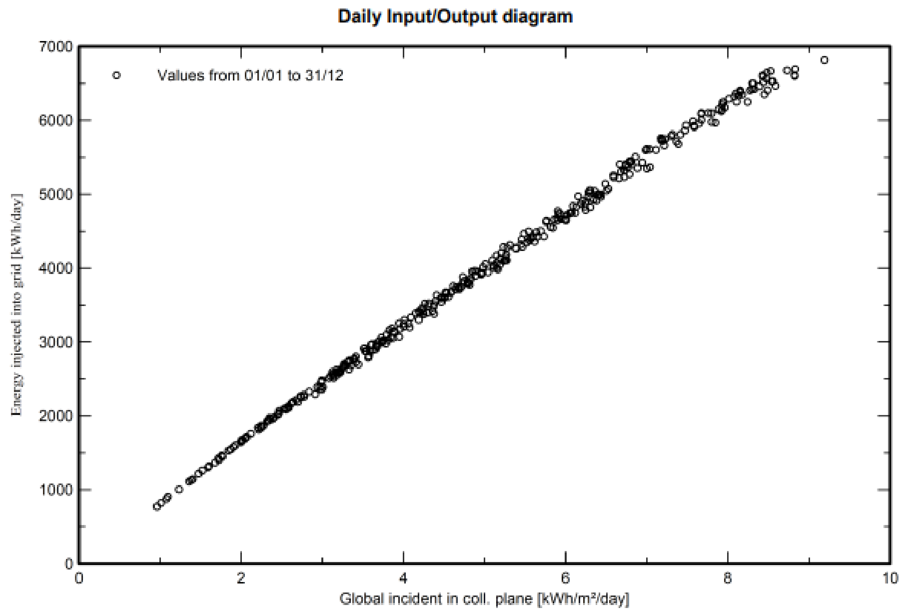
[49] N. R. Fulbright, "Agrivoltaic: Solar powering the future of agriculture," December 2017. [Online]. Available: https://www.nortonrosefulbright.com/en-ug/knowledge/publications/b54c815d/agrivoltaic—solar-powering-the-future-of-agriculture.

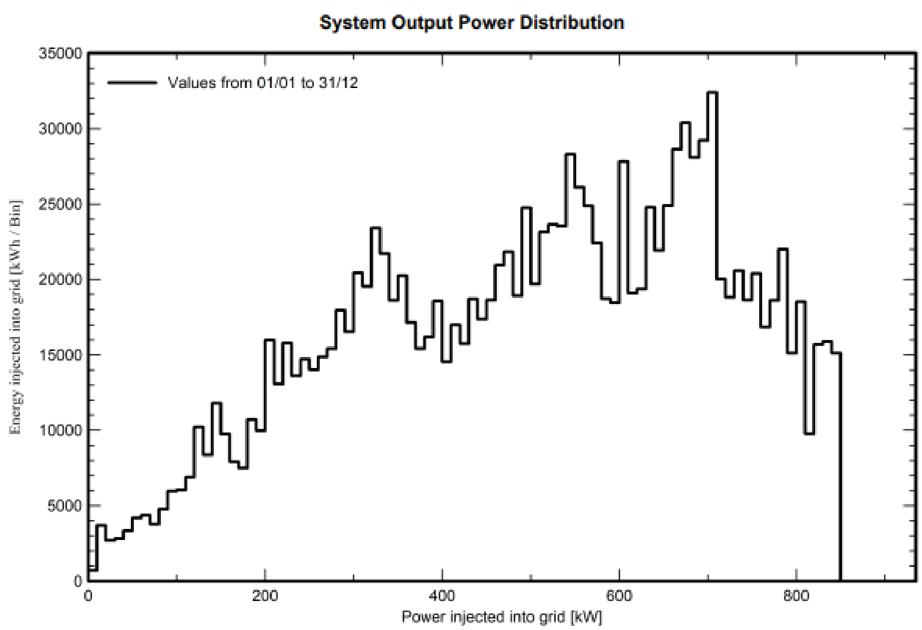
[50] Republic of Rwanda, "Admistrative structure," October 2021. [Online]. Available: https://www.gov.rw/government/administrative-structure.

[51] G. P. Price, "Electricity prices," March 2021. [Online]. Available: https://www.globalpetrolprices.com/electricity_prices/.

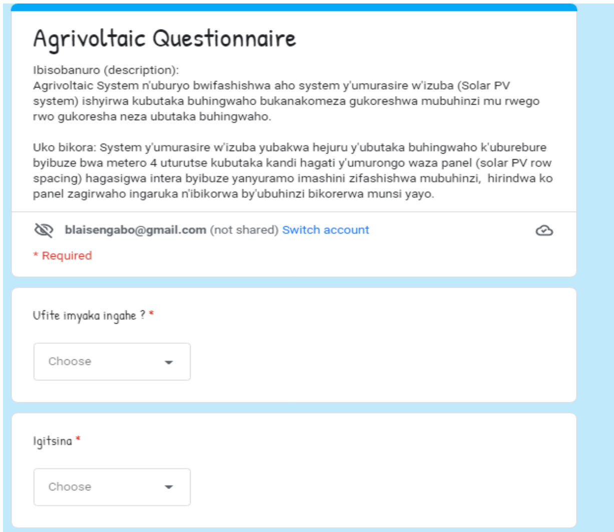
Appendix: System Report of the configuration selected and Survey Questionnaire and Feedback

A. System Report





B. Survey Questionnaire & Feedback



Agrivoltaic Questionnaire

Ibisobanuro (description):
Agrivoltaic System n'uburyo bwifashishwa aho system y'umurasire w'izuba (Solar PV system) ishyirwa kubutaka buhingwaho bukanakomeza gukoreshwa mubuhinzi mu rwego rwo gukoresha neza ubutaka buhingwaho.

Uko bikora: System y'umurasire w'izuba yubakwa hejuru y'ubutaka buhingwaho k'uburebure byibuze bwa metero 4 uturutse kubutaka kandi hagati y'umurongo waza panel (solar PV row spacing) hagasigwa intera byibuze yanyuramo imashini zifashishwa mubuhinzi, hirindwa ko panel zagirwaho ingaruka n'ibikorwa by'ubuhinzi bikorerwa munsi yayo.

blaisengabo@gmail.com (not shared) Switch account

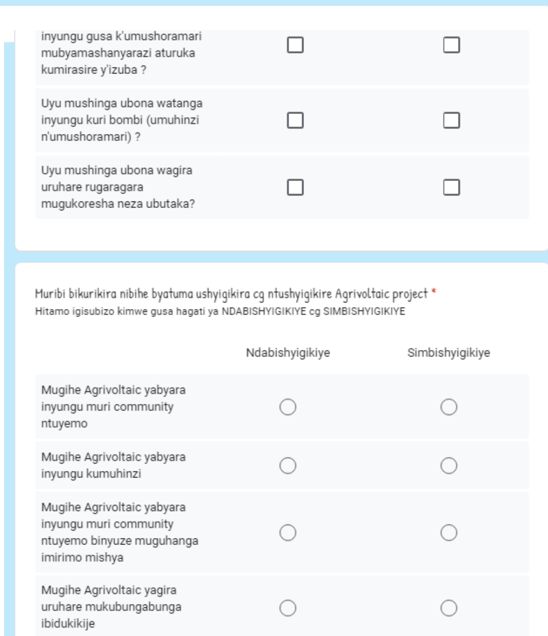
* Required

Ufite imyaka ingahe ? *

Choose

Igitsina *

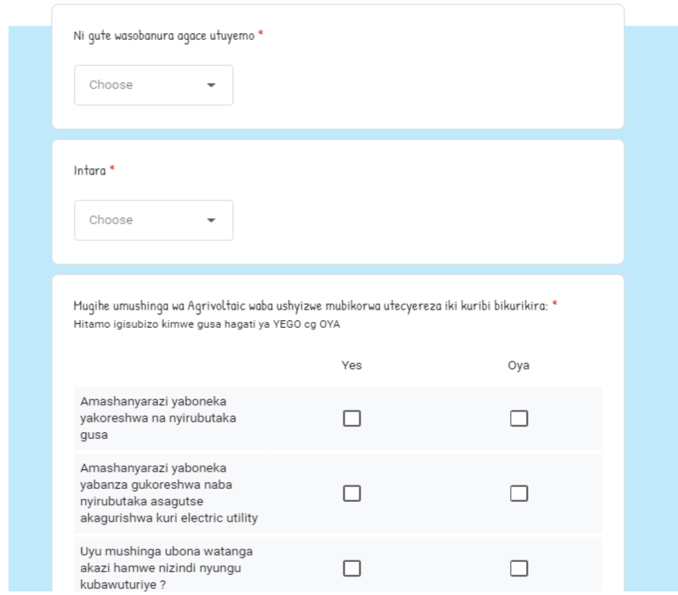
Choose



inyungu gusa k'umushoramari mubyamashanyarazi aturuka kumirasire y'izuba ?	☐	☐
Uyu mushinga ubona watanga inyungu kuri bombi (umuhinzi n'umushoramari) ?	☐	☐
Uyu mushinga ubona wagira uruhare rugaragara mugukoresha neza ubutaka?	☐	☐

Huribi bikurikira nibihe byatuma ushyigikira cg ntushyigikire Agrivoltaic project *
Hitamo igisubizo kimwe gusa hagati ya NDABISHYIGIKIYE cg SIMBISHYIGIKIYE

	Ndabishyigikiye	Simbishyigikiye
Mugihe Agrivoltaic yabyara inyungu muri community ntuyemo	○	○
Mugihe Agrivoltaic yabyara inyungu kumuhinzi	○	○
Mugihe Agrivoltaic yabyara inyungu muri community ntuyemo binyuze muguhanga imirimo mishya	○	○
Mugihe Agrivoltaic yagira uruhare mukubungabunga ibidukikije	○	○



Ni gute wasobanura agace utuyemo *

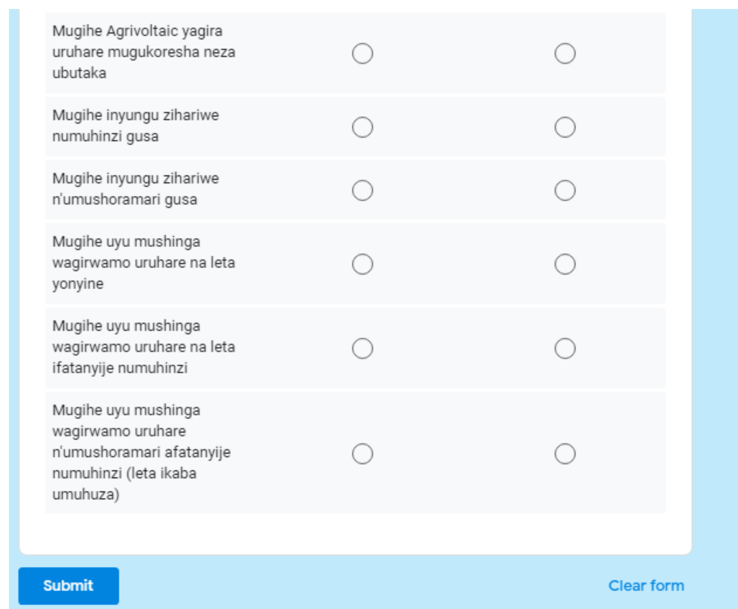
Choose

Intara *

Choose

Mugihe umushinga wa Agrivoltaic waba ushyizwe mubikorwa utecyereza iki kuribi bikurikira: *
Hitamo igisubizo kimwe gusa hagati ya YEGO cg OYA

	Yes	Oya
Amashanyarazi yaboneka yakoreshwa na nyirubutaka gusa	☐	☐
Amashanyarazi yaboneka yabanza gukoreshwa naba nyirubutaka asagutse akagurishwa kuri electric utility	☐	☐
Uyu mushinga ubona watanga akazi hamwe nizindi nyungu kubawuturiye ?	☐	☐



Mugihe Agrivoltaic yagira uruhare mugukoresha neza ubutaka	○	○
Mugihe inyungu zihariwe numuhinzi gusa	○	○
Mugihe inyungu zihariwe n'umushoramari gusa	○	○
Mugihe uyu mushinga wagirwamo uruhare na leta yonyine	○	○
Mugihe uyu mushinga wagirwamo uruhare na leta ifatanyije numuhinzi	○	○
Mugihe uyu mushinga wagirwamo uruhare n'umushoramari afatanyije numuhinzi (leta ikaba umuhuza)	○	○

Submit

Clear form

No.	Age level	Gender	Province	Energy from AVS consumed by land owner only	Energy from AVS first consumed by land owner, the rest sent to the grid	AVS can create jobs to the community?	AVS can create income only to farmer?	AVS can provide income only to energy investor	AVS Can create income for both farmer and energy investor	AVS can offer a solution to land optimization	If AVS provide benefits in my community	If AVS provid income to local farmers
1	Between 30 - 50	Male	Kigali City	No	Yes	Yes	No	No	Yes	Yes	Support	Support
2	Above 50	Female	Southern	No	Yes	No	No	No	Yes	Yes	Support	Support
3	Between 30 - 50	Male	Southern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
4	Between 18 - 29	Male	Northern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
5	Between 30 - 50	Female	Southern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
6	Above 50	Male	Western	No	Yes	Yes	No	Yes	Yes	Yes	Support	Support
7	Between 30 - 50	Male	Kigali City	Yes	Yes	Yes	No	No	Yes	Yes	Support	Support
8	Between 18 - 29	Female	Western	No	Yes	Yes	No	No	Yes	Yes	Support	Support
9	Between 30 - 50	Male	Southern	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Support	Support
10	Between 30 - 50	Male	Northern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
11	Between 18 - 29	Female	Western	No	No	Yes	No	No	Yes	Yes	Support	Support
12	Between 30 - 50	Male	Kigali City	No	Yes	Yes	No	No	Yes	Yes	Support	Support
13	Between 18 - 29	Female	Northern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
14	Above 50	Male	Eastern	No	Yes	Yes	Yes	No	Yes	Yes	Support	Support
15	Between 18 - 29	Male	Kigali City	No	Yes	Yes	No	No	Yes	Yes	Support	Support
16	Between 18 - 29	Female	Kigali City	No	No	Yes	No	No	Yes	Yes	Support	Support
17	Between 18 - 29	Male	Kigali City	No	Yes	Yes	No	No	Yes	Yes	Support	Support
18	Between 18 - 29	Female	Kigali City	No	Yes	Yes	No	No	Yes	Yes	Support	Support
19	Between 18 - 29	Female	Southern	No	Yes	Yes	No	No	Yes	Yes	Support	Support
20	Between 18 - 29	Male	Northern	No	No	Yes	No	No	No	Yes	Support	Support
21	Between 18 - 29	Male	Eastern	No	No	No	Yes	No	Yes	Yes	Support	Support
22	Between 18 - 29	Male	Eastern	Yes	Yes	Yes	Yes	No	Yes	Yes	Support	Support
23	Between 18 - 29	Female	Southern	No	Yes	Yes	No	No	Yes	Yes	Support	Support