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Master's Thesis

DOMESTIC SOLAR ENERGY AS SOLUTION FOR NON- CONNECTED RURAL AREAS

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Science in Renewable Energy

Submitted by

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(CASE STUDY: KAMONYI DISTRICT, RWANDA.)

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2019

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DEDICATION

To my precious family and parents

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature:.....Date.....

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This thesis has been submitted for examination with our approval as the university supervisor

Signature:.....Date.....

Dr Erneste MAZIMPAKA

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First, I am thankful to my husband, my sons, my parents and my siblings who have always encouraged me, supported me moral and spiritual. Your love, your inspiration is vast.

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ABSTRACT

The electricity demand is very high worldwide. The energy growing needs consideration of environment protection. Some alternatives have been taken such as using renewable energy. Peat, Thermal and Hydro are still in small scale in some African countries including Rwanda. Rwanda is under developing country and energy is the key component of the economy growth. The grid connection is less than the budgeted by the Rwandan Government, it is blocked by the country topography. The rural areas are the most suffered because some of them have means and continue to use traditional manners which results to the environment damages.

They are some alternatives such as using photovoltaic system.

It is in way this thesis is concentrating and looking on a design of a photovoltaic no connected to the national grid of 0.8 Kwh/day for a household in Kamonyi District as a chosen case study.

The goal of this design is to increase the number of household connected to off grid photovoltaic system.

The first part of the design focused on analysis of electricity to be consumed by the household considering the appliance in the house.

The second step of this design is the cost analysis of all needed components in order to involve the householder in the system design, costs of the system and let him have the character of ownership.

The result of this design helps in sizing the PV panel, battery capacity and converter to provide the required electricity to the household.

In this project the design and all simulation are done through PV SYSTEM V6.70 Software, excel software, books, scientific researches, survey, journals and different papers

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ABBREVIATIONS

GOR: Government of Rwanda
MW: Megawatt
SQ: Square
M²: meter square
Km: kilometer
KWH: kilowatt-hour
KWP: Kilowatt peak
GW: Gig watt
MM: millimeter
CU₂O: Cuprous Oxide
CUO: Cupric Acide
2H⁺: positive Hydrogen ions
SO₄⁻: Sulphate negative ions
ND: Second
TV: Television
Dr: Doctor
STC: Standard Test Condition
NGOs: Non-Governmental Organizations
ESMAP: Energy Sector Management Assistance Program
PMB: Rwanda Mining, & Gas Board
PVs: Standalone Solar Photovoltaic
MINIFRA: Ministry of Infrastructure
DC: Direct current
AC: Alternating current
AGM: Absorb Glass Mat

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CHAP I INTRODUCTION

Rwanda is an under developing country and energy is a main and important component of the economy growth and progress as all African countries. It is known that the current energy to be supplied is insufficient and is at high cost, this blocks and prevents the sustainable development factor. Rwanda's Vision 2020 key factor for the development process will be obtained by putting efforts in country economic growth, increasing private investments, citizen well being and economic transformation which is supported by a consistent and practical energy supply as highlighted by the Government.

The Rwanda Government (GoR) highlights the role of energy access as a fact of economic growth and development for the population. Some energy priorities have been set in which the Government, the private sector located in Rwanda and development partners have contributed enough to increase and distribution of on-grid and off-grid electrification, this shows that the priorities set were achieved and future projects have been set in order to increase the number of people accessing to energy as high as possible. [(REMA, 2000)

Energy is fundamental and essential to Rwanda's economy growth and development plans. The efficiency and growth of energy sector in Rwanda is the precondition and measurement of country's national goals achievements. It is shown by the fact that all other sectors are supported by energy in which housing electrification and urbanization, industrial processing, agro-processing, mining sector, tourism sector and IT services are included. The Energy Sector Strategic Plan(ESSP) is vital in delivering this.

The ESSP will ensure operational and achievement of the targets for the energy sector set by the National Strategy for Transformation (NST-1),guide the implementation and set follow ups of the National Energy Policy (REP). The ESSP functions and serves as a strategy and approach to interpret directives policy and principles in to physical and tangible measures required to reach medium-term targets, reflecting current resource controls ,risk and doubts. [(infrastructure M. o., 2018)]

The demand on electrical energy has been significantly increase due to the technological, citizen open minded and economic developments over the world. The use of renewable energies contributes to prevent and reduce global warming effects as it is a clean, green and

environmental friendly. Fossil fuel used at a high quantity nowadays will be exhausted over the time because they play a big role in climate change as they are finite. In order to protect our environment renewable energies are the perfect solutions to increase the access to electricity in remote areas, solar energy system should be effective with great importance as it is clean, sun fueled and green source of energy.

Sufficient electricity supply is vital to economic growth and expanding household electricity access. Capacity is now 218 MW, to speed up and cross up with increased electricity demand and to help in achievement of NST-1 goals, a pipeline of projects will be delivered to ensure demand is met, with an additional 15% reserve margin to increase reliability of power supply. Forecasting future electricity demand in a high-growth country is challenging and so annual analysis will be carried out.

Supply and demand side interventions will be used to ensure generation and demand remain aligned. The diversification of power sources will continue, with further peat transformed in to power and methane gas transformed in to power capacity planned, and the potential for solar, wind and geothermal to be further explored, alongside additional hydropower projects. This will reduce the use of expensive and polluting diesel generation and will permit Rwandan Government to lesser the durable period of cost of service and work towards a cost-reflective consumer tariff.[(infrastructure M. o., Energy sector strategic plan(2018-2019)-(2023-2024), 2018)]

Access to electricity has increased significantly in recent years, grid expansion is a slow process and it will take decades to reach all households, Off-grid technologies and commercial structures have developed significantly in recent years and now present a feasible different option to grid connections. No connected to grid subsectors development plan and strategies were set by Rural Electrification Strategy (RES) and have been published in June 2016. As off grid solutions targets, it is projected that 48% of all households will have their electricity necessities by 2024.[(Infrastructure i. o., 2018)]

Productive users utilize energy for activities that enhance income and benefit and include health and education facilities, public infrastructure and industry. The current connected productive users is 72% which will increase to 100%. Connecting productive users away from cities will support rural economic development and the sustainability of the sector as they have a higher ability to pay for energy services than households.

Due to energy sector street lighting will be expanded to all National Roads and urban roads. This results to crime reductions.[(Infrastructure M. o., energy sector strategic plan(2018-2019)-(2023-2024), 2018)]

As well as connecting new consumers, the reliability of electricity supply will be improved significantly. In 2016/17, the average customer of REG was without power for 36 hours. By 2024, this figure will be reduced to 14.2 hours. Further, the average number of interruptions in a year will be reduced from 229 to 91. These improvements will benefit both households and commercial consumers [(infrastructure M. o., strategic plan (2018-2019)-(2023-2024), 2018)]

Energy efficiency is a priority in energy sector, Government should set initiatives to improve energy efficiency from generation, transmission, distribution up to end users consumption. Some standards are set for efficiency such as distribution of LED's and efforts are designated in the HLTOs to reduce the current losses of 22% in transmission and distribution to 15%.This will result to financial performance of REG as well as reducing the environmental impact of the energy sector.[(Infrastructure M. o., Straategic plan(2018-2019)-(2023-2024), 2018)]

An ambitious HLTO is using to reduce the number of house hold using traditional cooking technologies,as the use of firewood results to health problem, environmental devastation, time loss in collection, new technology was introduced to Rwandan market as a good solution which is LPG and Gas

1.1 BACKGROUND AND MOTIVATION

In the last three decades Rwanda has experienced and suffered energy crises, this affected all sectors which participate in economy growth and country development. Because of its vision, targets, policies, execution strategies and plans set, Rwanda has begun to make great progresses and major improvements in electrification for the past few years. In 2010 the electricity generation was 100 MW, due to Rwandan vision the generation capacity has increased more than doubled to 216 MW by December 2017. (rural areas contributes 12% and urban area contributes 72%). [(Samuel BIMENYIMANA, 2018)], this clarified how the Rwanda power sector is among the fastest growing, and it offers occasions and motivations for those who are interested in energy sector business.

The Rwandan Government big target by 2023 and 2024 is to increase electricity generation capacity to 512 MW, It will satisfy 100% of Rwandan population consistently and sustainably. 52% of the population would be connected to the national grid, while the remaining 48% of population would be connected off-grid. [(Samuel BIMENYIMANA, 2018)].

Due to the radial nature of electricity transmission networks, the electricity generated in Rwanda from various power plants is distributed to business centers and urban areas through single lines. In rural areas, the cost of electricity is high because of geographical conditions which are not affordable, thus it pushes the village residents to move to cities.

1.2 COUNTRY PROFILE

Rwanda is one of the smallest countries on the African mainland and it is located in Central and East Africa. It has an area of 26,338 km² where land occupied 24,668 km² and water is 1,670 km² with 12,501,156 million estimated population in March 2018 [(world, 2018)]

It borders with Burundi in the South, Democratic Republic of Congo in the West, Tanzania in the East and Uganda in the North, few degrees south of the equator.

Rwanda is in the African Great Lakes region and is highly raised. The medium elevation point is at 1598 m, the lowest point is Rusizi River 950 m and the highest point is volcan KALISIMBI at 4,519m, its geography is conquered by mountains in the west and savanna to the east, with many lakes throughout the country. Rwandan climate is temperate to subtropical, with two rainy seasons and two dry seasons every year. This geographic position makes Rwanda likely source of renewable energy. [(engineering, 2019)]



Figure 1 Rwanda map [(map, 2019)]

1.3 PROBLEM STATEMENT

The Government of Rwanda (GoR) highlights the role of energy access as an important factor of economic growth for the Rwandan population. Future projects were set as a priority by the Government together with the private sector and development partners to participate in the meaningful increment of on-grid and off-grid electrification in the country[(development, 2016)]

Rwandan target by 2024 is 52% on grid and 48% off grid[(Africa, 2018)]

To achieve that target The Rwandan Government should put in force off grid system as solution for people with purchasing power which are not connected on grid.

1.4 GOALS AND OBJECTIVES

MAIN OBJECTIVE

The main vision and target of this thesis is to carry out a study of how to increase the number of people who can use off -grid domestic solar system.

SPECIFIC OBJECTIVES

The specific objectives of this project are:

- People with purchasing power can access and can be connected to the electricity in remote areas.
- conduct a study of solar energy design of a rural area house
- Proposing and exposing a basic solar home system to the market to let people choosing the cheapest one to be used among the presented systems on the Rwandan market.
- Conduct the cost analysis of selected components
- Clarify the advantage of using solar energy in Rwanda

1.5 RESEACH METHODOLOGY

In our research we will use different methods to obtain data and information such as:

- Collect data by sampling 2nd category UBUDEHE, people categorized in 2nd group are likely deserve electricity thus solar system is the solution.
- Analyze the efficiency of electricity consumption by a rural on- grid house to well conduct the study.
- Use questionnaires and interviews for records.

CHAP II.LITERATURE REVIEW

Renewable energy in Rwanda is growing perfectly and introduce new technologies which produce feasible, clean and green energy from different sources such as the wind, plants, sun and water. Therefore it offers energy in four important areas: electricity generation, air and water heating and cooling, transportation and rural (no connected to the national grid) energy services. According to the Rwanda Energy Group, in 2018, the total installed capacity of Rwanda's power generating plants was recorded at 218MW. Renewable sources of energy accounted for about 113.14 MW (52.4%) of total energy consumption in Rwanda[[(engineering, 2019)].

Renewable energy in Rwanda supplies clean energy which includes solar energy .It participates in fighting against climate change by preventing global warming situation[(N.Ghellai, 2015)].That is why Rwandan government is encouraging and supporting citizens and private companies to use renewable energies, by investing and be part of it.

Solar panels is the most important component in solar Energy system. Solar energy is mainly generated depending on the intensity of the sun rays reaching the solar panel and their wavelengths. [(Dr. M Narendra Kumar, 2014)].

Since 1980's solar energy was used for electrification and been introduced to Rwandan market.It was supported by donors and Non-Governmental Organizations(NGO'S).The study was conducted by ESMAP (Energy Sector Management Assistance Program) as World Bank project in 1991 provided an assessment of the market at that time. [(Bronckaers, 2012)].

2.1PV SOLAR ENERGY WOLRDWIDE

In 2018 solar photovoltaic (PV) global market increased slightly, but enough to surpass the 100 GWi level (including on-grid and off-grid capacity) for the first time, its Cumulative capacity increased approximately 25% to at least 505 GW.

Regardless of the single digit progress rate of the global market in 2018, solar PV has become the world's fastest growing energy technology, with gigawatt scale markets in an increasing number of countries.This compares to a global total of around of 15 GW. The energy price reduction involves Europe to highly demand on energy market.Renewable energy especially solar energy is growing progressively on international market for residential and commercial

applications.[REPORT CITATION REN21. 2019. Renewables 2019 Global Status Report (Paris: REN21 Secretariat). ISBN 978-3-9818911-7-1]

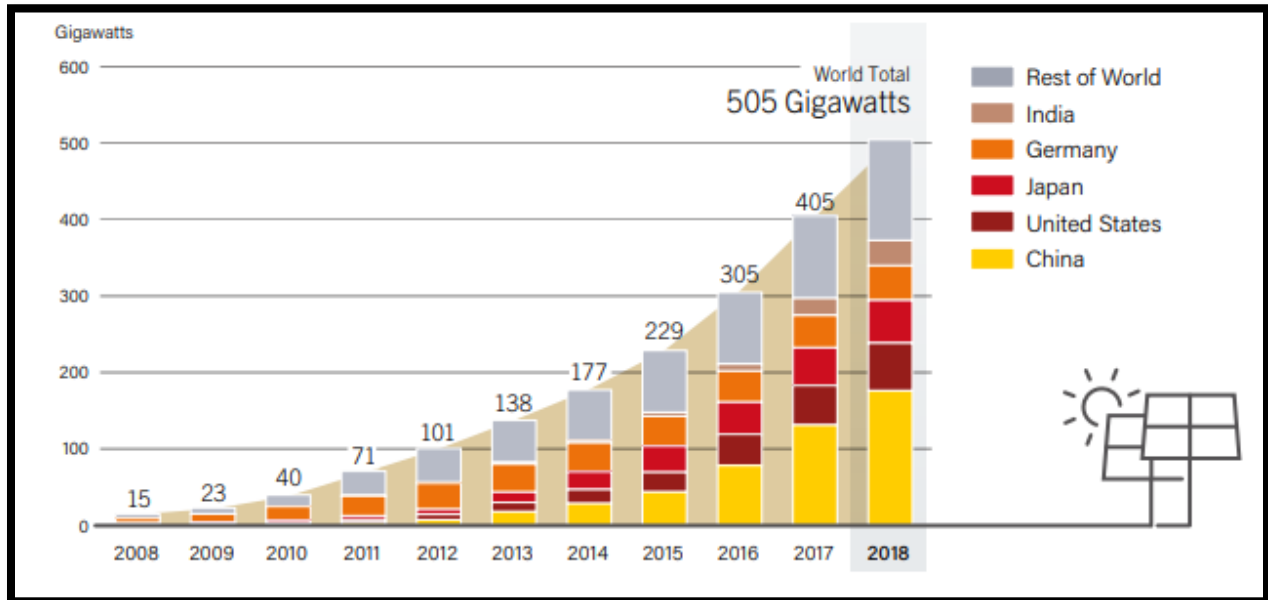


Figure 2:solar PV by country by region 2008-2018

2.2 SOLAR ENERGY IN AFRICA

Africa is fighting for its development, and as the energy is the key component of each region development, therefore all African countries stand and invest in solar source to increase electricity generation.

Africa has an exceptional solar resource that can be controlled and transformed into electricity generation and for thermal applications which can be used in different sectors involved in each country development and economy growth. Solar energy can be used in many scales such as household and industries. In Africa there are some regions with strong irradiation such as North Africa desert and some parts of Southern, East Africa, Sahelian and Tropical conditions also feature strong solar irradiation. Electrification demand in Africa is high than electricity generation, that is why many projects are taking place and been supported by each country government.

Collective installed capacity at the end of 2014 was 1334 megawatt (MW), which was ten times more larger than in 2009 (127 MW). South Africa is leading this rapid growth, adding nearly 780 MW between 2013 and 2014. Kenya has also seen sizable investments in solar PV, with 60 MW installed by 2014 (IRENA, 2015b). This accelerated growth will continue, as more than 14 GW of solar PV. [(IRENA, 2015)]

CHAP III RWANDA ENERGY SECTOR

Energy is the key concept of development of each country. And in all countries electricity is an important fact of recent technology and socio sector development and economic development. It participates in citizen lives improvement, industrial activities processing and job creations.

3.1 GOALS OF ENERGY SECTOR IN RWANDA

These government goals are set to ensure that citizens, industries, access to all energy products efficiently. The below energy policies are specific center global objectives:

- Supply to all Rwandan a guarantee, sufficient, consistent energy at a good
- Creating and supporting environment for increased private sector participation in energy supply and service provision by helping them and invest in their projects.
- Encouraging and invest in house hold end users, public institutions, industries, to use energy in normal range without waste for energy conservation
- Keep safe the environment in energy exploration, extraction, supply, and consumption to prevent damages to the environment and habitats;
- Promoting efficient services, safety in production, reasonable production, transportation of energy, procurement of required equipment, and safety distribution of energy;
- Developing and create the necessary institutional, organizational and labor capacity to increase accountability, clearness, national ownership and decentralized implementation capacity for sustainable energy service delivery. [(infrastructure M. o., energy sector in Rwanda, 2019)].

3.2 ELECTRICITY GENERATION

Installed capacity in Rwanda is at 218 MW, with 212.5 MW connected to the grid and an import option of 5.5 MW. This is an increase from the 160 MW installed at the time of the previous ESSP. The technology mix has also been diversified. Hydro makes up 45% of installed capacity, Diesel & HFO 27%, methane gas 14%, peat 7% and solar 6%.

The total installed power of 218 MW is not available steadily. The operation of the hydro units is limited by the water level in the upstream and their interdependence, and hydro availability lowers significantly during the dry season. In addition, the PV solar capacity is not significantly available during the evening peak hours. Further, losses are incurred on the transmission and distribution lines (about 2% of the total installed power) and some of the units may be unavailable during certain periods due to maintenance or failure. [(Infrastructure M. o., energy sector strategic plan, 2018)]

The Rwandan Government is still focus on strategies of increasing the electricity generation in order to achieve its goals.

3.3 ELECTRICITY ACCESS

Currently in Rwanda 51% Rwandan households have access to electricity, in which (37%) is connected to the national grid and (14%) is not connected to the grid. Rwandan target is to reach 100% of people accessing to electricity thus a national electrification plan has been well designed to confirm that this set target is reached in 7 years (by 2024).

The Government of Rwanda is promoting and supporting various sources of electricity such as solar home systems, some supporting policies have been approved to encourage people to make productive use of the power on the national grid, in order to association the demand and supply situation and prevent energy end user loss. In 5 years (by 2022), 100% productive users will be connected as targeted by Rwandan government.

The national Policy's approach on access to Electricity is that 52% of national population will be connected to national grid and 48% is Off-grid. Currently off-grid connection is at 14%. [(infrastructure M. o., energy sector in Rwanda, 2019)]

Many off grid projects are on way forward to increase the number of citizen accessing to electricity which contribute in economy growth and socio development.

3.4 MAIN SOURCE OF ENERGY IN RWANDA 2019

Energy is the key concept of development. The energy sector plays a pivotal role in supporting socio-economic transformation and has an inherently systemic link to the growth of other sectors of the economy. In order for the energy sector to leverage a most positive impact on the other sectors in a way that supports Rwanda's development; by Energy Policy formulation, development of Energy Sector Strategies and laws. Other key activities include monitoring of projects implementation under Rwanda Energy Group, stakeholder coordination, research and knowledge management.

The energy sector in Rwanda consists of three components: Electricity, Biomass and Petroleum, with each playing a key role in Rwanda's evolution.[(infrastructure M. o., energy sector in Rwanda, 2019)]

3.5RENEWABLE ENERGY IN RWANDA

Renewable energy is energy generated by natural processes that are not refill such as wind energy, solar energy,hydro energy, peat and methane

3.5.1 HYDRO POWER GENERATION

Hydro power generation in Rwanda opportunities exist in Micro and small hydropower projects as 333 major Rivers have been proven as potential sites for Micro hydropower through the country. It shares regional hydro power projects with East Africa (EAC) Partners.

Hydropower is the cheapest technology for electricity generation I Rwanda as his generating operations are cheap. Since 1960's has generated electricity to the Rwandan market.

Its overall potential generation is estimated at up to 400 M W, in which the current hydro capacity installed is 98.5 MW. [(Infrastructure M. o., energy sector stratrgic plan, 2018)]

Rwandan Hydropower plants are grid connected system, they include national and shared regional projects (Rusizi I and II HPPs). Hydropower produces 47% of the total installed capacity. Hydro power plants are either publicly possessed and operated, leased to private companies, or privately owned (IPP).

3.5.1.1 Mini and Small Hydropower

In Rwanda currently there are 11 micro hydropower plants existing in Rwanda as remote systems. They were originally developed and presented by the Government of Rwanda, and controlled, supervised, handled, controlled and managed by private sector to increase the private sector contribution, ownership in energy generation. There are also Pico-hydropower plants in the range of 1-10 kW which are either publicly operated by the local communities or entirely private.

3.5.1.2 in coming Medium Hydropower projects

- Nyabarongo II (43.5MW): This project was designed as a multipurpose project which is expected to be used in irrigation, to supply water, and to generate electricity as its main purpose. Nyabarongo River has been proven as dangerous to the daily living of citizen, to prevent it the project was also envisaged to moderate the continuous flooding downstream. The project is fully funded by the Government of Rwanda and its construction is expected to start end 2019 then completed in 2025.
- Rusizi III (145MW): This project is supported by World Bank, EU, AfDB financially among others with an expected investment capital of \$450 million and completion date in 2024, it is planned to generate 145 MW in which the power output will be shared by three partners as the project is being developed under CEPGL (Rwanda, Burundi and DRC). Rwanda will get an output equals to 48.3MW and the rest will be shared by Burundi and DRC equally.
- Rusumo Falls Hydro Electric Power (80MW) falls: The project is being developed and controlled by NELSAP (Rwanda, Burundi and Tanzania), it is funded by the World Bank. The construction of the project started in 2017 and is planned to be completed end 2020.



Figure 3: Nyabarongo hydro power plant generating 28 MW[(Esiara, 2014)]

3.5.2.BIOMASS

Biomass as source of energy in Rwanda covers 85% of all energy consumed. The subsector consumes wood based bio-products which are fuels developed from biological materials, such as wood and charcoal, and biogas derived from waste matter. Rural households use wood while urban households use charcoal as biomass for cooking. The biomass subsector is being informed by the development of the Biomass Energy Strategy (2018) to conduct a study and an analysis of supply and demand percentage of biomass and sets out a strategy to reduce dependence on wood and charcoal by citizens. National strategy for transformation sector has an important objective of exposing the number of households using traditional cooking technologies in order to achieve a sustainable balance between supply and demand of biomass through promotion of most energy efficient technologies.[] (infrastructure M. o., energy sector in Rwanda, 2019)



Figure 4 biogas plant in Rubavuprison[(Oswald, 2018)

3.5.3 PEAT

A study conducted in Rwanda shows that Rwandan peat swamp which covers an area of 50,000 hectares contains up to 155 million tones of dry peat. Near Akanyaru and Nyabarongo rivers and the Rwabusoro Plains regions reserve about 77% of peat.

The study supervised by the Government of Rwanda conducted, indicates a possibility of 150 MW for sod peat application and 117 MW for milled peat application electricity generation from exploitable peat reserves in a period of 30 years of operation.[(ltd(REG), 2018)]

There is 2 big peat power plant in Rwanda:

1. Gishoma 15 MW Peat to Power Project

The Rwandan Government started the development of the 15MW peat power plant in since 2010 located in Gishoma, Rusizi District. This project was conducted to reduce electricity shortage which the country was facing matches with a highly demand of electricity in the region where Gishoma is located results on cement factory expansion and county development. As the factory increasing the products the need of energy is growing progressively.

Nowadays the plant is working well and connected to the national grid. This is a great achievement to Rwandan government which shows that by working with effort and focus and by following the targets set other projects will succeed and be implement for sake of country and citizen development.



(ltd(REG), 2018)

2. Hakan Project

YUMN Ltd is designed to produce 80 MW peat fired power plant in South Akanyaru located in Southern province, Gisagara District and the project is to be developed as Public Private Partnership (PPP).

Once completed, the peat project is expected to increase 40% of national power capacity. By completing this project the Rwandan Government will benefit in two ways which are increasing electricity on national grid and bring more energy independence to the Country since it is meant to use 100% of domestic fuel leading to the reduction of imports.



(Itd(REG), 2018)

3.5.4 METHANE

Methane Gas in Rwanda is found in Lake Kivu located in the Eastern African Rift Zone and the DRC.

The area of 2,400 km² lake at a depth from 270m to 500 m contains high concentrations of naturally occurring methane gas (CH₄) and carbon dioxide (CO₂). This Lake contains about 300 billion cubic carbon dioxide and 60 billion cubic meters of CH₄ in which an estimated quantity of 120 to 250 million cubic meters of CH₄ is generated annually in the Lake.

By using extraction technology, the Methane in Lake Kivu can generate 700 MW of electricity over a period of 55 years and Rwanda's share of the total generation potential is about 350 MW, with the rest being DRC's share.

Lake Kivu has the capacity to generate 120 million to 150 million m³ of CH₄ per year, representing a power potential of 90 to 130 MW.

Existing Methane-to-Power Projects in Rwanda

1. KivuWatt project: It is planned and constructed to generate 100 MW in 2 phases as the first one commissioned in December 2015 currently producing around 26.4 MW. The following ongoing phase will produce 75 MW as planned. This project is managed by a subsidiary of Contour Global (US-based Company)
2. Kibuye Power (KP1) :This project is located in Rubavu district and has been generating around 3MW of electrical power with the design capacity of 3.6 MW. Symbion Power

Lake Kivu Ltd is mobilizing for reviewing its construction in order to increase the generation capacity from 3.6 M to 50 Mw is in process.

3. Symbion Power Lake Kivu Ltd as a additional of Symbion Power LLC is planning to generate 50 Megawatt (MW) methane gas to power project. The Power plant will be located on Nyamyumba sector in Rubavu District. (infrastructure M. o., energy sector in Rwanda, 2019)



Figure 5:KIVU lake methane[(Julius, 2019)]

3.5.5 SOLAR ENERGY

Rwanda is located in East Africa at approximately two degrees below the equator. It borders with Burundi in the South, Democratic Republic of Congo in the West, Tanzania in the East and Uganda in the North.

Rwanda is geographical location endows it with sufficient solar radiation equal to 5kWh/m²/day approximately and peak sun hours of 5 days per day. It normally characterized by Savannah climate.

Rwanda's Total on-grid installed solar energy is 12.08 MW, and to reduce the cost of electricity generation, households far away from the planned national grid coverage are encouraged to use standalone solar photovoltaic (PVs). The outline strategies have been approved in 2016 by the Rural Electrification Strategy in Rwanda through which Rwanda's households could "have

access to electricity through the most cost effective means by developing programs. This will facilitate both the end users to access less costly technologies and increase private sector participation in the provision of these solutions” (MININFRA, RES, 2016). By 2024 48% of households will be connected to the off grid power system as it is planned and emphasized by the energy sector strategic plan. [(infrastructure M. o., energy sector in Rwanda, 2019)]



Figure 6:Agahozo shalom youth village[(Parvaresh, 2015)]

3.5.5.1 EXISTING SOLAR PROJECTS IN RWANDA

- Mount Jali in Kigali 250KWp Solar Plant: It is constructed on the top of Mount Kigali, it is operating successfully from July 2008. This project of 250 Kw grid connected was funded, constructed, owned and operated by German municipal power company Stadtwerke Mainz as signed by the Government of Rwanda with German state Rhineland-Palatinate.
- Rwamagana Solar Power Plant (8.3 MW): The plant is located near Agahozo Sharlom Youth Village in Rwamagana District, It was commissioned in February 2015 and built in collaboration with Gigawatt Global at a cost of US23.7 million. The plant is the first utility-scale solar power plant in East Africa.
- Nasho Solar (3.3 MW) power plant: The project was funded by the Howard G Buffett Foundation in collaboration with the Ministry of Agriculture and was established and

commissioned in 2017 for generation of 3MW solar energy to power-up the irrigation system and the surplus is used to light up homes in the area.

Future projects

- Feasibility studies are being conducted with different partners on the development of 30MW power plant with storage facility in the Eastern province. [(infrastructure M. o., energy sector in Rwanda, 2019)]

3.5.5.2 SOLAR IRRADIATION IN RWANDA

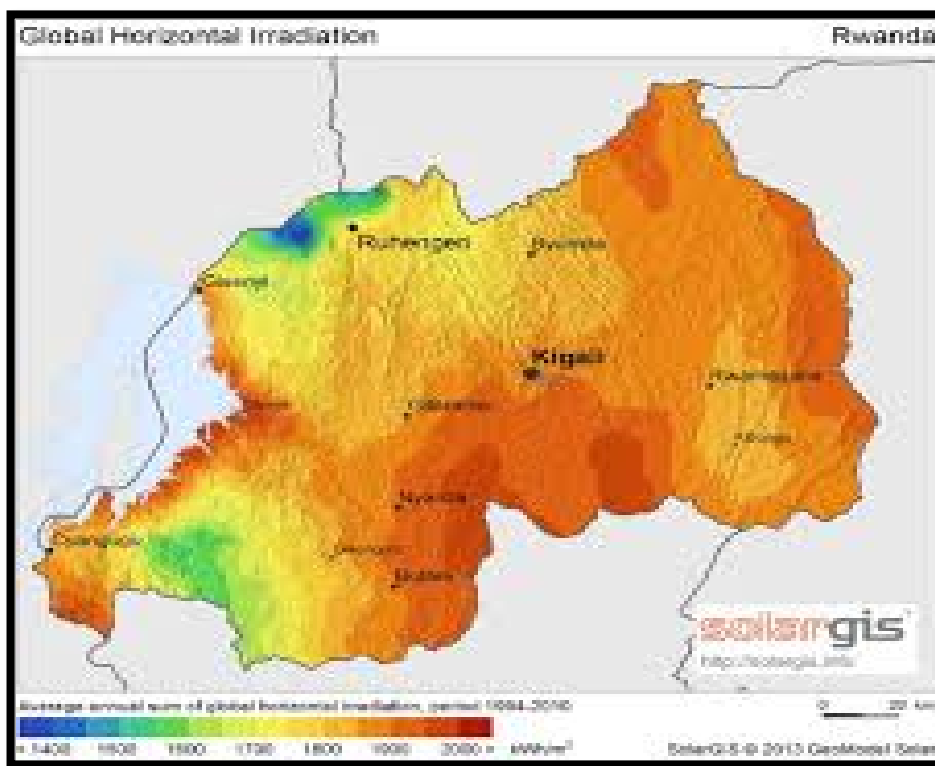


Figure 7 Global horizontal irradiation map for different district in Rwanda:[(A Ameur, 2015)/.]

The below graph describes and shows monthly average daily solar irradiance in Rwanda the whole year of 2017.

CHAP IV DOMESTIC SOLAR ENERGY

4.1 INTRODUCTION

Domestic solar energy

A solar radiation is a non-exhausting reservoir of energy. The power of solar energy emitted into the cosmic space equals 4×10^{20} MW. The part of the solar energy reaching the earth atmosphere is about 1018 kWh/year. This energy is higher than energy stored in all recognized fossil fuels sources.

The PV effect has been discovered in 1839 by Bequeral during the study of two metallic electrodes in a conducting solution. Bequeral observed an appearing voltage when electrodes were illuminated. , the photovoltaic process can be demonstrated using copper. A chemical reaction occurs between copper and oxygen. The copper atoms and oxygen atoms form molecules called copper oxide. Copper forms two different oxides. They are cuprous oxide, Cu_2O , and cupric oxide, CuO . Cuprous oxide, a red crystalline material, can be produced by furnace methods and is a semiconductor. The copper surface can be oxidized by overheating, creating a layer of black cupric oxide. When the black layer flakes off, the red cuprous oxide layer under eathis exposed. When sunlight strikes the cuprous oxide, free electrons will move into saltwater, then into a clean copper plate, into the wire, through the meter, and back to the cuprous oxide plate. [(Ahsan)]

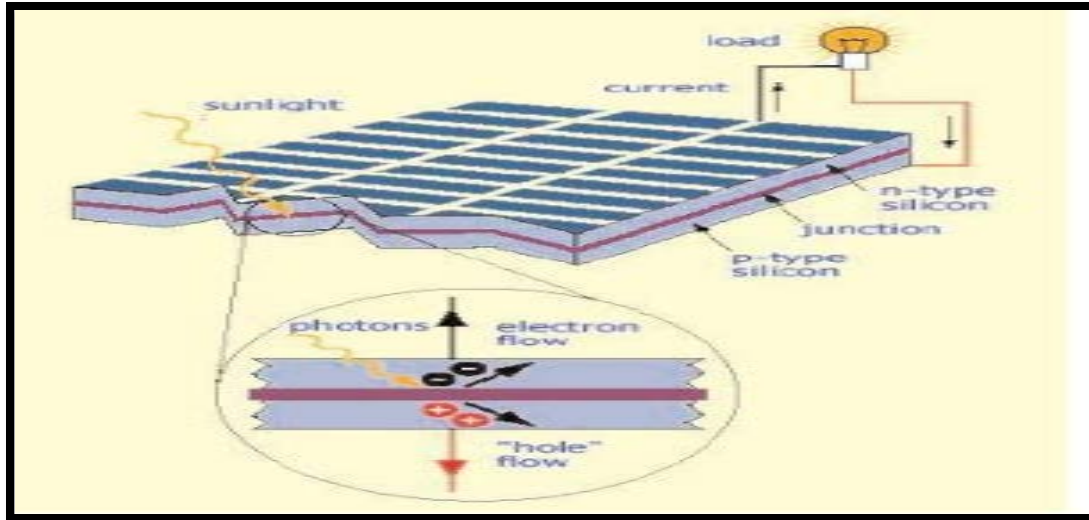


Figure 8:Photovoltaic cell make[(Ahsan)]

A photovoltaic (PV) cell is a device that produces electricity directly from sunlight. Photovoltaic cells are made of at least two layers of semiconducting material. The first layer has a positive charge then the next layer has a negative charge.

The semiconducting material absorbs photons from the light when sunlight hits the photovoltaic cell. In this process electrons are liberated from negative layer to positive layer. This flow of electrons constitutes an electric current, which can be captured in a circuit connecting the two layers.[(Ahsan)]

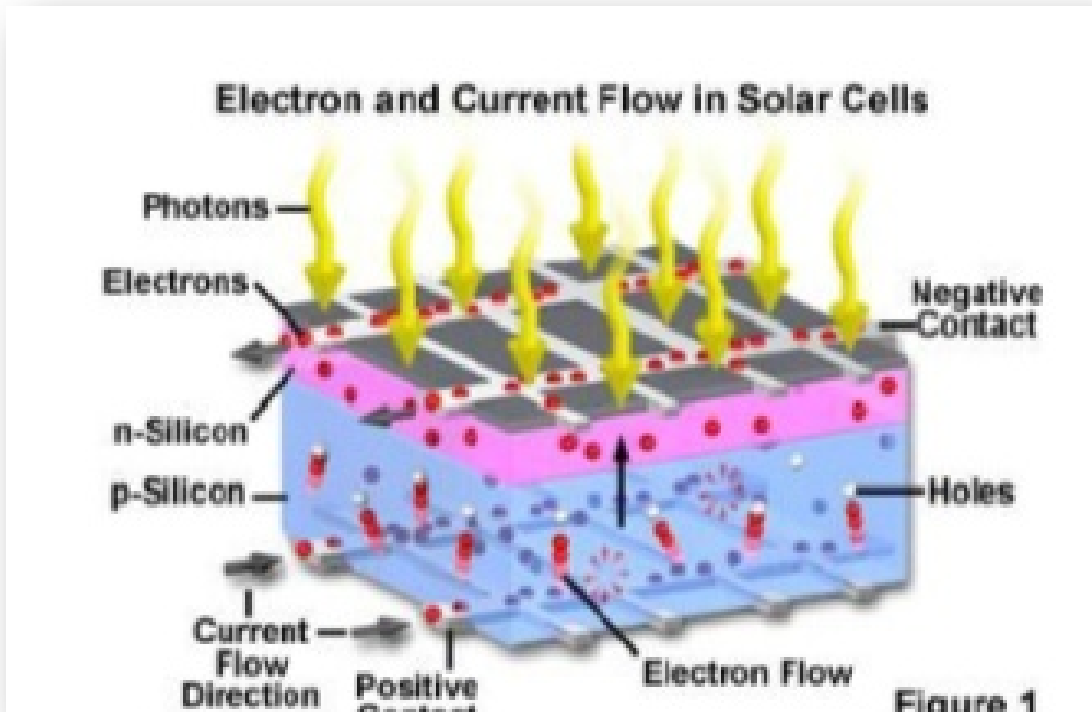


Figure 9: photovoltaic cell construction [(Ahsan)]

4.2 SOLAR HOME ENERGY SYSTEM

PV components are used for solar energy conversion, power conditioning and energy storage and for power distribution

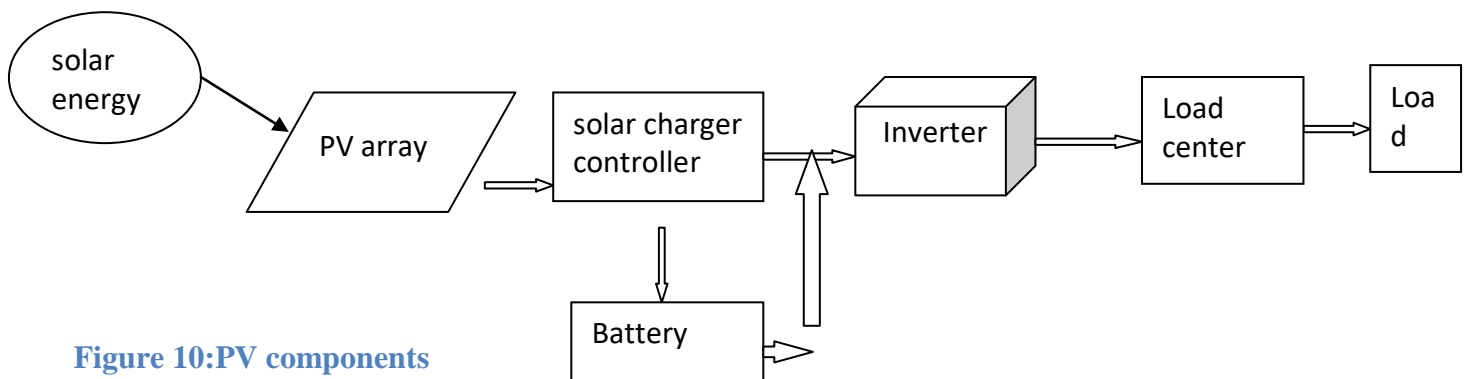


Figure 10: PV components

4.2.1 SOLAR PANEL

A PV module consists of several interconnected solar cells (typically 36 connected in series) summarized into a single, long-lasting, stable unit in order to protect them from mechanical damages and to prevent water to corrode the electric contact and metal grid of the top surface of the solar cell. As shown the single cell can be meet all cited mechanical damages which result to inefficient of the cell. [(Module structure)]

A fundamental characteristic of a photovoltaic system is that power is produced only while sunlight is available [(batteries overview)]. The current and power output of photovoltaic solar panels are approximately proportional to the sun's intensity. At a given intensity, a solar panel's output current and operating voltage are determined by the characteristics of the load . To generate large amount of power output, solar cells are connected in a compound structure within the PV module and the output power from a typical solar cell is approximately equal to 1 watt. [(solar oanel efficiency)]

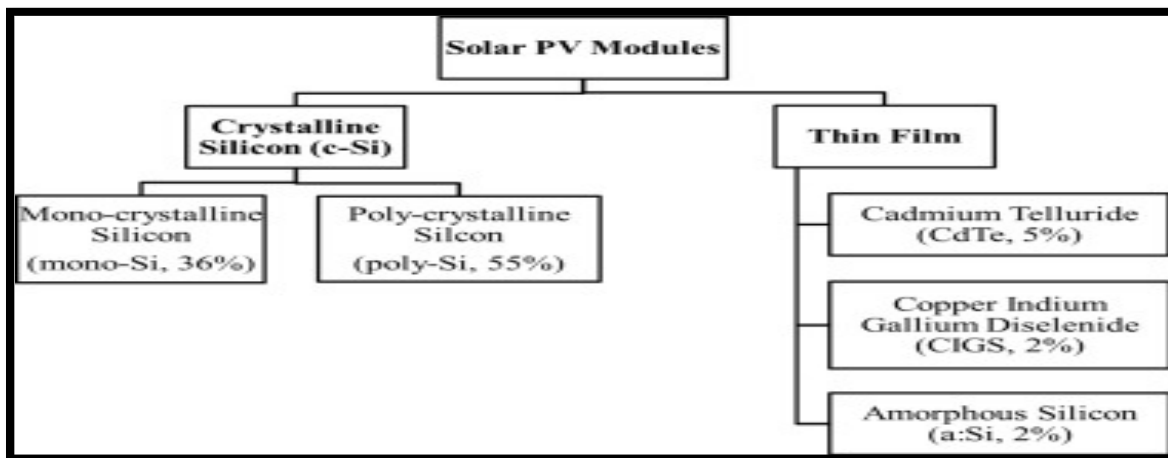


Figure 11:Solar PV modules [(Renewable enrgy and sustainable energy reviews, 2015)]

4.2.1.1 BASIC TYPE SOLAR PANELS

4.2.1.1.1 MONOCRISTALLINE SOLAR PANEL

The most efficient and expensive solar panels are made with Monocrystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Long silicon rods are produced which are cut into slices of 0.2 to 0.4mm thick discs which are then processed into individual cells that are wired together in the solar panel. [(www.freesunpower.com)]



Figure 12 :Monocrystalline solar panel[www.freesunpower.com)]

4.2.1.1.2 POLICRISTALLINE SOLAR PANEL

They are made with Polycrystalline cells which are a little less expensive & slightly less efficient than Monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals. This is what gives them that remarkable crushed glass appearance. Like Monocrystalline cells, they are also then sliced into wafers to produce the individual cells that make up the solar panel. [www.freesunpower.com)]



Figure 13: Polycrystalline solar panel[www.freesunpower.com]

4.2.1.1.3 AMORPHOUS SOLAR PANEL

These are not really crystals, but a thin layer of silicon deposited on a base material such as metal or glass to create the solar panel. These Amorphous solar panels are much cheaper, but their energy efficiency is also much less so more square footage is required to produce the same amount of power as the Monocrystalline or Polycrystalline type of solar panel[www.freesunpower.com]



Figure 14: Amorphous panel [www.freesunpower.com]

For implementation of this standalone system design, I will use mono crystalline PV solar module.

MONOCRYSTALLINE ADVANTAGES

- Monocrystalline solar panels are made out of highest grade silicon, this gives them the highest efficiency rate of 15-20%. SunPower produces the highest efficiency solar panels on the U.S. market today. Their E20 series provide panel conversion efficiencies of up to 20.1%. SunPower has now released the X-series at a record-breaking efficiency of 21.5%
- Monocrystalline silicon solar panels are space-efficient. Since these solar panels give away the highest power outputs, they also require the least amount of space compared to any other types. Monocrystalline solar panels produce up to four times the amount of electricity as thin-film solar panels. This shows how they are the great ones
- Monocrystalline solar panels living time is the longest than other type of pannel. Most solar panel manufacturers put a 25-year warranty on their monocrystalline solar panels and this is considered why during cost analysis.
- Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.[www.freesunpower.com)]

4.2.1.2 EFFECT OF TEMPERATURE ON THE SOLAR PANEL PERFORMANCE

Temperature consideration is the important key factor of electricity production by the solar panels. Most of the world think that as the sun is very hotter and stronger affects the production of electricity, but the output of most solar panels is measured under Standard Test Conditions (STC) – this means a temperature of 25 degrees Celsius or 77 degrees Fahrenheit.

It is important to understand the effect of the temperature on the output performance of the solar module. Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons travel. The module temperature has a dramatic effect on voltage parameters. Open circuit voltage and maximum voltage are decrease with increasing module

temperature. This is due to an increase in resistance of the circuit that results from an increase in temperature. [(research, 1982)]

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4.2.2 SOLAR INVERTER

A solar inverter is used to convert the generated DC voltage into AC voltage from PV array as required by different AC loads and also insuring the best performance of the PV modules. The efficiency of an inverter varies per load demand and their efficiency curve is usually provided by the manufacture. An inverter provides a factor of compatibility, but its use can reduce the array's available electricity if it is not suitably designed to match the electrical load [(Franklin, 2019)],that is why a designer has to take a good attention on all required to get a good design to prevent those incompatibilities.

basically an inverter is a set of automatic switches that provide polarity reversals from the solar array.

Energy from an array or a battery bank is direct current (DC). This will provide for DC loads such a lights, fans, pumps, motors, and some specialty equipment. However, if the energy is to be used to power loads that operate on alternating current (AC), as what is found in a residence, the current needs to be converted.[(Franklin, 2019)] and it helps in household appliance selection.

4.2.3 SOLAR CHARGER CONTROLLER

A charge controller is used to regulate the amount of charge going into the battery from the module to keep it from overcharging. Charge controllers can vary in the amount of amperage they can regulate. Some models will include additional features such as connecting and operating DC loads, and regulating energy going to a load based on the amount of charge in a battery. During daylight, the array sends power to the controller and to the battery. The controller monitors the level of energy to keep the battery fully charged. At night, when the array is not sending energy, the controller allows the battery to energize the load as demanded.

[(Franklin, 2019)]

There are four basic types of controllers used for small PV systems.

- Shunt controller - redirects or shunts the charging current away from the battery. These controllers require a large heat sink to dissipate the excess current. Most shunt controllers are designed for smaller systems producing 30 amperes or less.
- Series controller - interrupts the charging current by open-circuiting the PV array. This switching controller is thus limited by the current handling capability of the components used to switch the dc current.
- Single stage controllers - disconnect the array when the battery voltage reaches the high voltage level.
- Multistage controllers - allow different charging currents as the battery nears full state-of charge. This technique also provides a more efficient method of charging the battery. As the battery nears full SOC, its internal resistance increases and using lower charging current wastes less energy

4.2.4 SOLAR BATTERY

The Energy storage represents a critical part of any energy system, and chemical storage in the form of a battery is the most frequently employed method for long term storage. In any photovoltaic system that includes batteries, the batteries become a central component of the overall system which significantly affect the cost, maintenance requirements, reliability, and design of the photovoltaic system.[(Renewable energy and sustainable energy reviews, 2015)]

The most commonly used battery for residential PV applications is the lead-acid battery. The solar user should look for a deep-cycle battery designed for renewable energy systems. There are two types of lead-acid batteries: flooded lead-acid (FLA), sealed absorbed glass mat (AGM). The battery voltage can vary from 2, 6, and 12 volts.

If the total voltage needs is greater than what one battery can provide, a number of batteries are connected together to form a bank. The life cycle of a battery can be lengthened if the battery is not discharged all the way to 0% charge. A reasonable design is to have batteries discharge to 50% then recharge to full. However, this design may require having more batteries in the bank. Batteries used in solar systems are classified as deep-cycle batteries and may be discharged up to 80% of its storage capacity[(Franklin, 2019)]

4.2.4.1 BATTERY SPECIFICATIONS

DEPTH DISCHARGE

It is the percentage of how the battery withstand discharge and this depends on its construction. The common batteries have electric active lead alloy plates immersed in mild acid electrolyte. The more massive plates shows that the battery can withstand the cycle of discharge and recharge[(battery characteristics, 2019)].

Considering depth discharge we have two types of batteries:

- Shallow cycle: These batteries are lighter, less expensive, short life time and should not be discharged more than 25%
- Deep cycle: These are used in standalone Photovoltaic as they are thicker and withstand at 80% of their rated capacity

BATTERY TEMPERATURE CORECTION AND LIFE TIME

Batteries are sensitive to the temperature, warm batteries do not provide power as cold ones, this means that they have to be kept in good condition.

They life time depend son considering many factors such as: charge & discharge rate, depth of discharge, number of cycle and their operating temperature.

SAFETY PRECAUTION

The lead-acid battery is an energy pack. It is quite sensitive to abuse. When treated in a wrong way, it is easy to pass over the limits to unstable conditions.

- Never stress the battery mechanically, electrically or thermally beyond the limits.
- The tools used for connecting batteries have to be insulated to avoid the potential shorting of batteries. Plastic tubes or plastic tape can easily be used for home manufacturing of insulated tools.
- Protect eyes and skin Safety goggles must always be worn when working with batteries. Rubber gloves should preferably be used to avoid skin contact with the electrolyte. Special clothing is recommended to avoid droplets of acid destroying the normal dress. Such droplets are not always recognized until the clothes are washed and the acid has already made holes in the dress.
- Large amounts of water should be used for rinsing if acid has come into contact with the skin, clothes or the construction of the installation.
- Explosions may result from different abuse situations. An explosion forces the cell case to burst and parts will fly around together with a spray of acid.
- The battery should be protected against short circuit by an electrical fuse sized correctly to protect the battery from currents above the maximum load and charge values. The fuse is preferably placed in the middle of the voltage string in the battery pack. The location of the fuse in the middle of the voltage string will be safer if a shortcut only involves some part of the battery. In a small 12V monoblock battery system the fuse should be placed as close as possible to the positive terminal.

- When assembling the parts of the installation, never connect the battery terminals until all cabling is finished and checked for faults. Mechanical abuse may well result in an explosion.
- Protect the battery from pieces that could fall down on the battery or be injected from the side. Mechanical damage to the battery may result in an explosion, which starts as an internal short circuit when the plates or connectors of different polarity are contacting each other as a result of the damage.
- A gas explosion is commonly created by an external spark. When batteries are fully charged and in the gassing mode, the internals of the cells are filled with an explosive gas mixture and gas is issuing through the vents. This gas is highly explosive and a cigarette, a match or even by an electrical spark, can easily ignite it. [(Franklin, 2019)

4.3 ENERGY TARGETS GOALS IN RWANDA

These targets represent the key areas of progress to be achieved through the duration of the ESSP and will be measured under the NST-1 reporting framework. Beneath these HLTOs further targets will be monitored by the Ministry of Infrastructure (MININFRA)

- The energy generation capacity increased to meet all energy demand and to maintain a 15% reserve margin .
- improve reliability of electricity supply by reducing 14.2 per year the average number of power interruptions and reducing to 91.7 the average number of hours without power.
- Ensure and emphasis electricity household access to increase until 100%.
- Ensure that the productive user access to electricity increased to 100%.
- Provide existing and new major national and urban roads street lights as economy development picture and security purpose.
- Make sure that distribution, transmission and commercial losses are reduced to 15%.
- Reduce 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 [(Infrastructure M. o., energy sector strategies plan (2018-2019)-(2023-2024), 2018)]

4.4 SOLAR HOME SYSTEM SIZING

Sizing a photovoltaic system for a stand-alone photovoltaic power system involves a five step process which will allow the photovoltaic system designer or user to accurately size a system based on users projected needs, goals and budget. These steps are:

- Estimating the Electric Load
- Sizing and Specifying an Inverter
- Sizing and Specifying Batteries
- Sizing and Specifying an Array
- Specifying a Controller

4.4.1 ESTIMATING THE ELECTRIC LOAD

Before sizing the array, the total daily energy in Watt-hours (E), the average sun hour per day, and the DC-voltage of the system (VDC) must be considered in order to design the array.

Individual load	Qty	Volt	Amps	=Watt AC	*Use hrs/days	*use dys/weeks	/7days/weeks	Average Watt days/hrs
AC total connected Watts				T.watts	AC average daily load			T Watts

Calculation of total energy consumption

To avoid over sizing system losses must be considering

Calculation of peak power

Calculation of total current needed

Calculation of module whether connected in series or in parallel

All these calculations will help to determine the total number of modules to be used

4.4.2. SIZING OF BATTERY

- Calculation of the amount of rough energy
- Calculation of safe energy
- Then calculation of the each battery capacity
- After knowing the batteries capacity, we calculate the number of batteries to be used
- At the end calculation of how batteries will be connected.

4.4.3 SIZING CONTROLLER

- Calculation of a good controller by considering short circuit current connected in parallel and safety factor. This must withstand the maximum current produced by array and maximum load current.

4.4.4 SIZING INVERTER

- The actual power calculated from appliances that will run at the same time must be considered to choose a perfect inverter.

4.4.5 SIZING WIRES

- Selection of correct size and type of wires is the key of a good performance and results.

CHAP V DATA COLLECTION AND CALCULATIONS

5.1 SITE SELECTION

KAMONYI district is located in Southern province with 655.5 km² and 340,501 population. It is located.

5.2 ENERGY SECTOR

SECTOR	OUTPUT	INDICATOR	BASELINE	TARGET
Increased access to electricity	Electricity connection increased	% of household connected to electricity	13.3% of household are connected to electricity.	14.5% to be connected to electricity

(Kamonyi, 2015)

KAMONYI DISTRICT MAP

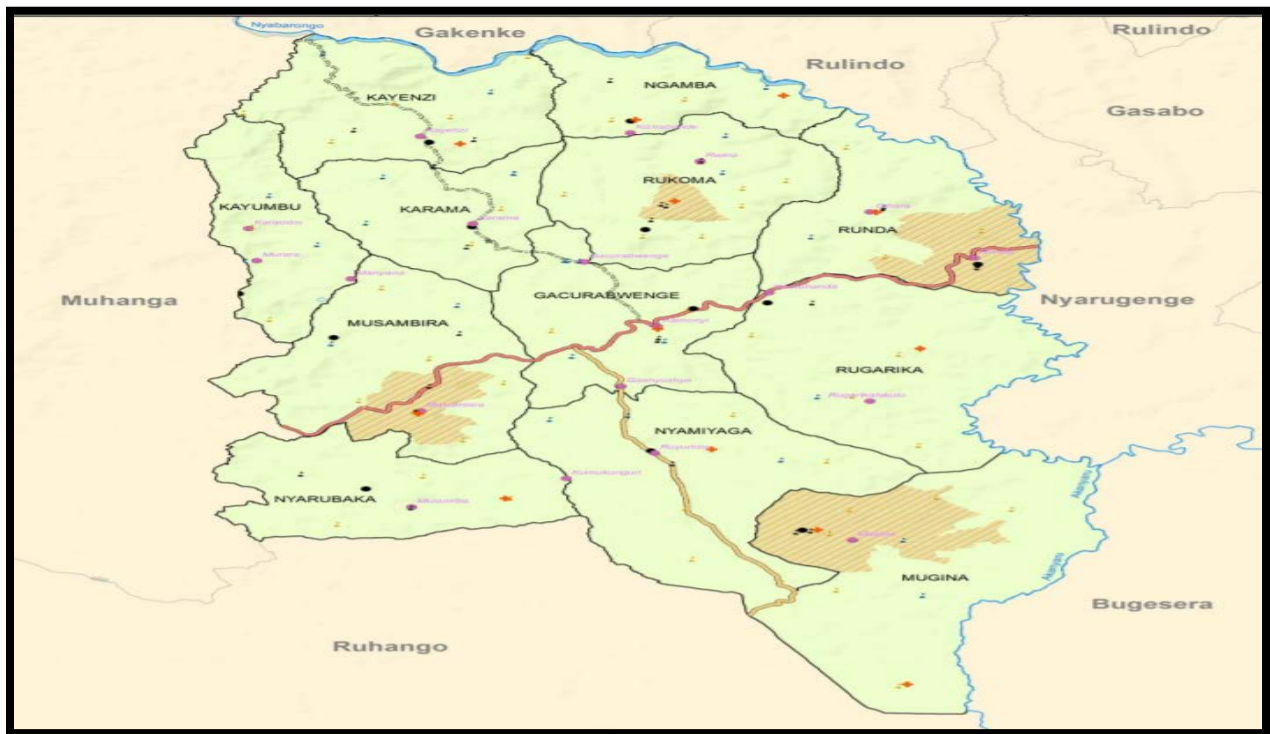
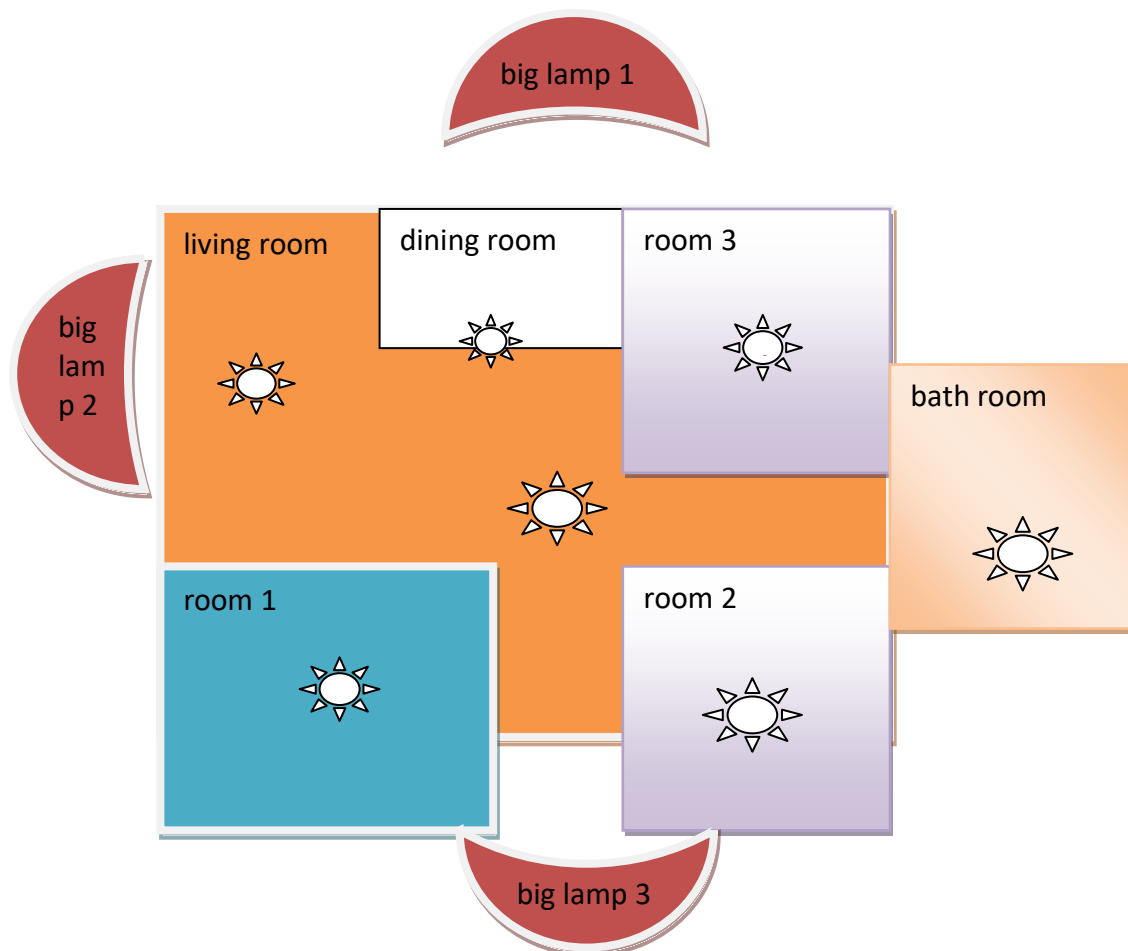


Figure 15: Administrative map of KAMONYI District [(statistics, 2015)]

5.3 CALCULATIONS BY USING SOFTWARE

5.3.1 HOME DESING

- 3 rooms
- Dining room
- Living room
- Bath room



Annual values Number

	Number	Power	Use	Energy
Lamps(LED/fluo	6	2W/lamp	5h/day	60Wh/day
TV/PC/mobile	1	60W/app	4h/day	240 Wh/day
Domestic appliances	1	40 W/app	3h/day	120 Wh/day
Big lamps	3	5W tot	8h/day	120 Wh/day
USB	1	50 W tot	2h/day	100Wh/day
Sand by consumers			24h/day	120Wh/day
Total daily energy				760 Wh/day

Table 1: Annual values Number

5.3.2 PV SYSTEM V6.70 SOFTWARE

PVsyst is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. PVsyst is designed to be used by architects, engineer, and researchers. It is also a very useful educative tool. It includes a detailed contextual Help menu that explains the procedures and models that are used, and offers a user-friendly approach with guide to develop a project. PVsyst is able to import meteo data from many different sources, as well as personal data. PVsyst presents results in the form of a full report, specific graphs and tables, and data can be exported for use in other software.

Management of the project: For a given project (a defined site and meteo), you can construct several variations for your system (“calculation versions”).

System design board: The system design is based on a quick and simple procedure:

- Specify the desired power or available area
- Choose the PV module from the internal database
- Choose the inverter from the internal database

Specialized tools are also provided for the evaluation of the wiring losses (and other losses like the module quality), the mismatch between modules, soiling, thermal behavior according to the mechanical mounting, system unavailability, etc.

Simulation and results report: The simulation calculates the distribution of energies throughout the year. Main results:

- The total energy production [MWh/y] is essential for the evaluation of the PV system's profitability
- The Performance Ratio (PR [%]) describes the quality of the system itself.
- The specific energy [kWh/kWp] is an indicator of production based on the available irradiation (location and orientation (<https://elect-engg.com/tag/pvsyst-software>))

5.3.3 CALCULATIONS

Stand Alone System: Simulation parameters

Project : offgrid

Geographical Site Kamonyi District Country Rwanda

Situation:

- Latitude -1.95° S and Longitude 29.87° E
- Time defined as Legal Time Time zone UT+2 Altitude 0 m Albedo 0.20

Meteo data: Kamonyi District Meteonorm 7.1, Sat=100% -

Synthetic Simulation variant :

- New simulation variant
- Simulation date 23/05/19 07h10

Simulation parameters: System type Stand-alone system

Collector Plane Orientation : Tilt 15° , Azimuth 0°

Models used Transposition Perez Diffuse Perez, Meteonorm

PV Array Characteristics

- **PV module** :Si-mono ,Model **TDB156X156-60-P 225W**
- Original PV syst database :Manufacturer is Sun Earth Solar Power Co Ltd
- Number of PV modules: In series 1 modules In parallel 1 strings
- Total number of PV modules :Nb. modules 1 Unit Nom. Power 225 Wp
- Array global power: Nominal (STC) 225 Wp At operating cond. 198 Wp (50°C)
- Array operating characteristics (50°C) :U mpp 26 V I mpp 7.6 A
- Total area: Module area 1.6 m² with of Cell area 1.4 m²

PV Array loss factors

Thermal Loss factor:

- U_c (const) 20.0 W/m²K
- U_v (wind) 0.0 W/m²K / m/s

Wiring Ohmic Loss:

- 1 Global array res. 58 mOhm
- Loss Fraction 1.5 % at STC

Series Diode Loss :

- Voltage Drop 0.7 V
- Loss Fraction 2.4 % at STC

Module Quality Loss: Loss Fraction 1.5 %

Module Mismatch Losses :Loss Fraction 1.0 % at MPP

Strings Mismatch loss: Loss Fraction 0.10 %

Incidence effect, ASHRAE parametrization:

- IAM = 1 - b₀ (1/cos i - 1)
- b₀Param. 0.05

System Parameter:

System type :Stand Alone System

Battery Model

- Open 12V / 100 Ah
- Manufacturer: Generic

Battery Pack Characteristics Voltage:

- 24 V Nominal Capacity 100 Ah
- Nb. of units 2 in series
- Temperature Fixed (20°C)

Controller Model:

- Universal controller with MPPT converter
- Technology MPPT converter Temp coeff. -5.0 mV/°C/elem.

Converter Maxi and EURO :efficiencies 97.0 / 95.0 %

Battery Management control: Threshold commands as SOC calculation

- Charging SOC = 0.92 / 0.75 i.e. approx. 27.1 / 25.1 V
- Discharging SOC = 0.20 / 0.45 i.e. approx. 23.6 / 24.4 V

User's needs : Daily household consumers Constant over the year average 0.8 kWh/Day

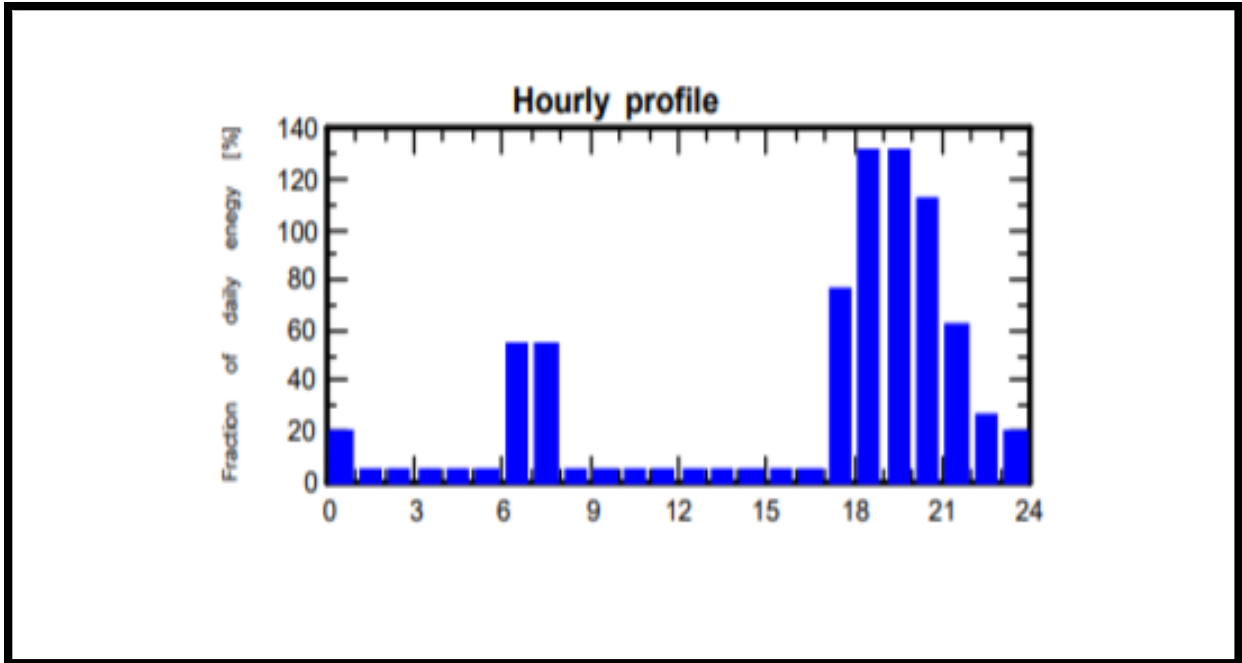


Table 2:Hourly profile

Main system parameters

System type: Stand alone

PV Field Orientation: tilt 15° azimuth 0°

PV modules Model :TDB156X156-60-P 225W Pnom 225 Wp

PV Array :Nb. of modules 1 Pnom total 225 Wp

Battery Model :Open 12V / 100 Ah Technology Lead-acid, vented, plates

Battery Pack :Nb. of units 2 Voltage / Capacity 24 V / 100 Ah

User's needs Daily household consumers: Constant over the year Global 277 kWh/year

MAIN STIMULATION RESULTS

System Production:

- Available Energy 299.2 kWh/year
- Specific prod. 1330 kWh/kWp/year
- Used Energy 267.0 kWh/year
- Excess (unused) 19.5 kWh/year

- Performance Ratio PR 65.72 %
- Solar Fraction SF 96.25%

Loss of Load :

- Time Fraction 4.2 %
- Missing Energy 10.4 kWh/year

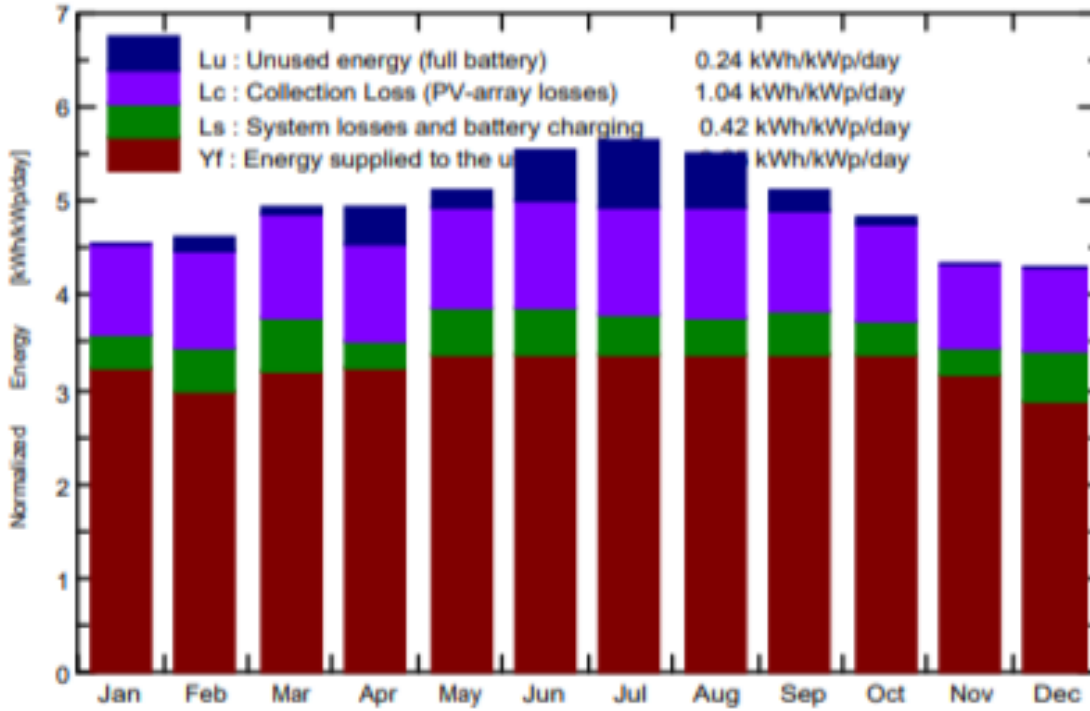


Table 3: Normalized production(per installed KWp): Normal power 225 KWp

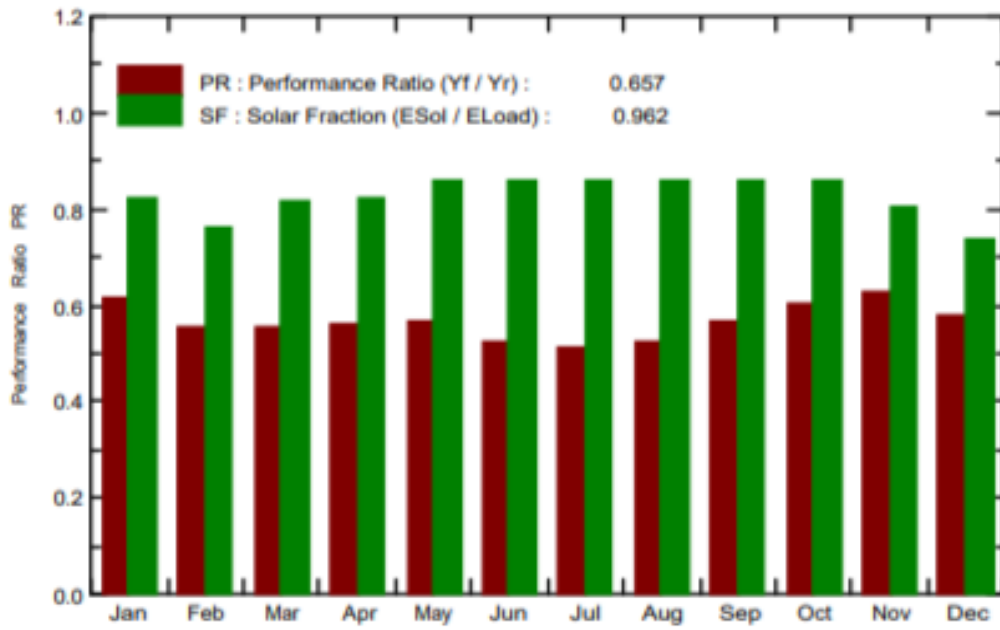


Table 4: Performanceration(PR) and solar Fraction(SF)

New simulation variant

	GlobHor kWh/m ²	GlobEff kWh/m ²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	155.1	134.8	23.02	0.002	0.985	22.58	23.56	0.958
February	137.8	124.6	20.92	0.955	2.436	18.84	21.28	0.886
March	155.9	147.7	24.83	0.524	1.215	22.35	23.56	0.948
April	144.7	143.3	24.53	2.504	0.978	21.82	22.80	0.957
May	148.3	153.3	26.36	1.287	0.000	23.56	23.56	1.000
June	152.0	161.9	28.12	3.621	0.000	22.80	22.80	1.000
July	160.4	169.6	29.72	4.868	0.000	23.56	23.56	1.000
August	162.0	165.5	28.62	4.001	0.000	23.56	23.56	1.000
September	153.6	148.6	25.44	1.405	0.000	22.80	22.80	1.000
October	157.4	144.1	24.56	0.381	0.000	23.56	23.56	1.000
November	142.2	124.6	21.34	0.000	1.438	21.36	22.80	0.937
December	148.8	127.4	21.75	0.000	3.360	20.20	23.56	0.857
Year	1818.3	1745.4	299.22	19.548	10.411	266.99	277.40	0.962

Table 5:Balance and main results

Legends:

- Glob Hor: Horizontal global irradiation
- Glob Eff: Effective Global corr. for IAM and shadings
- E Avail: Available solar energy
- E unused: Unused energy(full battery)loss
- E Miss: missing energy
- E user: energy supplied to the user
- E load: Energy need of the user(load)
- SolFrac: solar fraction(E used/Eload)

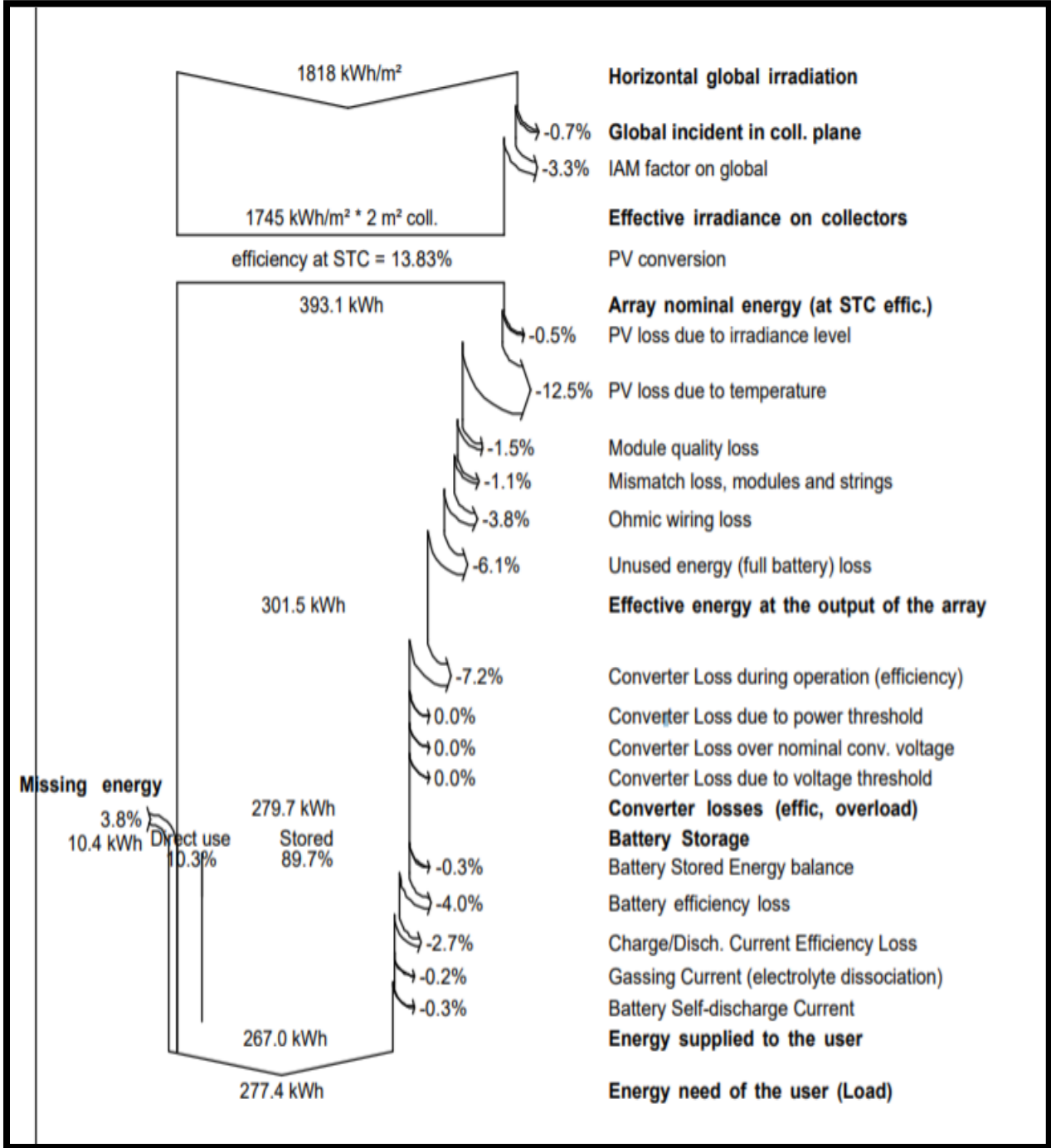


Table 6: Loss diagram over the year

5.4 COST ANALYSIS

The implementation of the proposed design for the household needs the clear cost analysis to convince the householder. The cost to be considered are:

- cost of PV module, controller, converter and other accessories (combiner box, surge arrester, mounting box, meter, wiring),man power and installation.

WORK REQUIRED AND THE COST

- A site visit
- Installation of the photovoltaic components.

S/N	PRODUCTS	QUANTIT Y	DESCRIPTION	COST/UN	TOTAL AMOUNT(Rwf)
1	SOLAR PANELS 225 W	1	TDB156X156-60-P-225W	170,000	170,000
2	BATTERY	2	OPEN 12 V/100Ah	100,000	200,000
3	CHARGER CONTROLLER	1	Maxi and EURO efficiencies MPPT	25,000	25,000
4	MPPT CONVERTER 800W	1		45,000	45,000
5	LABOUR,TRANSP ORT&MAINTANANC E	1		500,000	500,000
6	OTHER MINOR ACCESSORIES	1		120,000	120,000
	TOTAL AMOUNT				1,060,000

Table 7 :Cost estimation

5.4. ENERGY PER UNIT COST

We proposed that life time of this PV system is 10 years life time thus we calculate the cost of the energy per unit by the design.

- Total cost=1,060,000 Rwf
- Average daily bright sunshine hours=6 hours
- Estimated designed capacity=0.8Kwh/Day
- Average energy produced per day= $0.8 \times 6 = 4.8$ Kwh
- Energy to be produced in 20 Years= $4.8 \times 10 \times 356 = 21,900$ Kw
- Cost per unit of energy produced in 10 years= $1,60,000 / 21900 = 48,4$ Rwf

5.5 CHALLENGES AND STRATEGIES

5.5.1 CHALLENGES

The major challenges in the solar energy sector are:

- Poor infrastructure for generation
- Transmission and distribution it requires initial capital
- Convincing people to use this system
- Follow up of preventive maintenance by considering do and do not on the system.

5.5.2 STRATEGIES TO BE TAKEN BY THE GOVERNMENT

- Government will establish a mechanism to allow low-income households to access modern energy services through a basic solar system as a basic necessity.
- Government will establish a risk-mitigation facility targeting the private sector such that solar products will be made available on financial terms that the population can afford
- Mini-grids will be developed by the private sector with Government playing a key role in identifying sites and establishing a framework through which these can become financially viable investments. [(Infrastructure i. o., 2018)]

5.5.3 STRATEGIES TO BE TAKEN BY THE CLIENT

- The client should follow the do and do not given by the engineer
- The client should conduct the preventive maintenance on the system to keep it in a good condition.
- Keep working with the government

CHAP VI CONCLUSION AND RECOMMANDATION

The stand alone system as renewable energy is the perfect way to help households to access to electricity when not connected to the grid. PV system is clean ,green, fueled by the sun and environmental friendly. It helps the reduction of fossil fuel usage and traditional manner usage by citizen.

This thesis consist of a design of a standalone solar PV system which will supply energy to a household with means but located in an area where the electricity distribution is difficult in order to support the government to reach the load connectivity goal in Rwanda. The design will help the Rwandan citizen to be involved in the system, to know the do and do'nt on the system basic maintenance knowledge and will help them to have the spirit of owner ship and team working.

Daily load demand consideration helps in sizing of perfect PV array, battery, solar controller, solar inverter(AD-AC) to be used in the design.

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