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DEPARTMENT OF ENVIRONMENTAL ENGINEERING

POTENTIALS OF ELECTRICITY GENERATION FROM SOLAR ENERGY FOR THE GAROUA CITY COUNCIL: ENERGY DEMANDS, EQUIPMENT, COSTING AND LAYOUT

A thesis submitted in partial fulfilment of the requirement for the degree of Master of Engineering (MEng) in **Environmental Engineering.**

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DEDICATION

This work is dedicated to the entire Nkongmick and Forwencheng families.

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ABSTRACT

Cameroon has experienced economic growth accompanied by increasing energy demand and inadequate supply. Yet, it has abundant resources of renewable energy that are still undeveloped. It would therefore be important to consider alternative ways through which electricity can be supplied continuously and reliably to all communities. The sun, one of the many existing resources, could be maximized to have a constant energy supply in the Garoua city council because the area is endowed with sunshine for most parts of the year. This work aimed to size equipment, evaluate the environmental benefits and estimate the cost of using solar energy for electricity generation for the Garoua city council. To attain the objectives, quantitative and qualitative research methods were used through the administration of questionnaires to the local population. Three villages were chosen in this council as a case study to design a solar plant based on load estimation. From the results, the total daily energy required by the population was estimated at 1239 kWh. This result was then used in PVsyst (Photovoltaic system) software to simulate the feasibility as well as the performance of the system. It resulted that, a total of 1080 panels (each panel having a power of 350 W) are needed to produce average annual energy of 761.997 MWh under standard test conditions with an annual system performance ratio of 55.2 %. The battery capacity needed to store the energy produced was calculated to be 416.40 kAh requiring a total of 288 batteries (2V, 3470 Ah capacity each). Finally, an analysis of the estimated cost of the project and environmental benefits were carried out. The capital cost was estimated at 838 300 792 Frs and CO_2 mitigation of 165.54 tons/year. With this data, it was concluded that theoretically, the generation of electricity from solar energy is feasible, can satisfy the population's needs and pose no danger to the environment.

Keywords: Garoua, Solar energy, Electricity, Load estimation, Photovoltaic system, Cost evaluation.

RESUME

Le Cameroun a connu une croissance économique accompagnée d'une demande énergétique croissante et d'une offre insuffisante. Pourtant, elle possède d'abondantes ressources d'énergie renouvelable qui ne sont pas encore développées. Il serait donc important d'envisager d'autres moyens de fournir l'électricité de façon continue et fiable à toutes les collectivités. Le soleil, l'une des nombreuses ressources existantes, pourrait être maximisé pour avoir un approvisionnement en énergie constante dans le conseil municipal de Garoua parce que la région est dotée de soleil pour la plupart des parties de l'année. Ces travaux visaient à dimensionner l'équipement, à évaluer les avantages environnementaux et à estimer le coût de l'utilisation de l'énergie solaire pour la production d'électricité pour le conseil municipal de Garoua. Pour atteindre les objectifs, des méthodes de recherche quantitatives et qualitatives ont été utilisées par l'administration de questionnaires à la population locale. Trois villages ont été choisis dans ce conseil comme étude de cas pour concevoir une centrale solaire basée sur l'estimation de la charge. D'après les résultats, l'énergie quotidienne totale nécessaire à la population a été estimée à 1239 kWh. Ce résultat a ensuite été utilisé dans le logiciel PVsyst (système photovoltaïque) pour simuler la faisabilité ainsi que les performances du système. Il en résulte que, un total de 1080 panneaux (chaque panneau ayant une puissance de 350 W) sont nécessaires pour produire une énergie annuelle moyenne de 761,997 MWh dans des conditions d'essai standard avec un rapport de performance annuel du système de 55,2 %. La capacité de la batterie nécessaire pour stocker l'énergie produite a été calculée à 416,40 kAh nécessitant un total de 288 batteries (2V, 3470 Ah capacité chacun). Enfin, une analyse du coût estimatif du projet et des avantages environnementaux a été effectuée. Le coût en capital a été estimé à 838 300 792 Frs et l'atténuation des émissions de CO_2 à 165,54 tonnes/an. Ces données ont permis de conclure que, théoriquement, la production d'électricité à partir de l'énergie solaire est réalisable, peut satisfaire les besoins de la population et ne présente aucun danger pour l'environnement.

Mots-clés : Garoua, Energie solaire, Electricité, Estimation de la charge, Système photovoltaïque, Evaluation des coûts.

LIST OF SYMBOLS AND ACRONYMS

CO_2	Carbon dioxide
$	Dollars
%	Percentage
µm	Micrometer
Ac	Alternating Current
ALCC	Annualized lifecycle cost
Am	Air mass
Dc	Direct current
Eneo	Energy of Cameroon
GIS	Geographical information system
IEA	International Energy agency
kAh	Kilo Ampere hour
Kg	Kilogram
kWh/m2/d	kilo Watt hour per meter squared per day
LCC	life cycle cost
MINADER	Ministry of Agriculture and Rural Development
MINEE	Ministry of Energy and Water Resources
MTOE	Million tons of oil equivalent
MWh	Mega Watt hour
NIG	Northern interconnected grid
PV	Photovoltaic
RE	Renewable energy
SAPV	Stand-alone photovoltaic system
STC	Standard test condition
Uel	Electrical energy unit
VAT	Valued added taxed

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GENERAL INTRODUCTION

Context

Recently, the world has witnessed an increase in energy demand coupled to faster depletion of natural gas, coal and crude oil reserves as well as negative impacts of fossil fuels to the environment. In 2019, the share of the world primary energy consumption by source was nuclear at 4 %, natural gas at 24 %, hydropower at 6 %, oil at 33 %, coal at 27 % and renewable energy (solar, biomass and wind) at 5 %. Driven by higher energy demand, the world's primary energy consumption rose by 2.9 % to reach 13,865 MTOE, 84 % of which came from fossil fuels, while global energy-related CO_2 emissions showed a growth rate of 1.95 % to a historic high of 33 891 MTOE (Rapier, 2022). This continuous energy demand in the world market coupled with the rise in energy prices has significantly drawn attention to the need for renewable energy (RE) sources which are immensely available and have the potential to efficiently satisfy an appropriate portion of the worlds energy need while minimising environmental pollution and health hazards associated with the use of natural gas, coal and crude oil (Abubakar et al., 2015).

Africa as a continent is blessed with abundant energy sources, but the imbalance between electricity production and distribution remains an issue in Sub-Saharan Africa (SSA) countries (Shaaban et al., 2014). Based on the International Energy Agency (IEA, 2020), 51.6 % of Saharan Africa population are without access to adequate electricity. This is due to disparity in their development across the whole continent. In examining Africa’s energy consumption in comparison to regions such as the Middle East, North America, Latin America and Europe, it is obvious that Africa has one of the lowest per capital consumption of energy.

Cameroon as many other third-world countries in Africa is faced with the challenge of providing reliable, sustainable and well-distributed network of electric power across urban and rural areas of the country. The state of electric power infrastructure is not the best and a lot needs to be done urgently to improve the generation, transmission and distribution of electric power in Cameroon. There have been numerous government policies and programs to rapidly expand the installed capacity from 62.7 % of electric energy in 2018 to 100 % by 2035 as part of the government’s efforts to reach its emergent plan (Kidmo et al., 2021).

Problem statement

Cameroon just like most third-world countries faces the enormous challenge of providing electricity to every citizen. Despite the availability of abundant reserve of energy resources such as crude oil, natural gas, hydropower, biomass, solar and wind. However, these areas are still weakly valorised and the country relies mostly on hydropower energy for electricity production (73 %) with a constant power outage and low coverage of rural areas (14 %) (Muh et al., 2017). In the Northern interconnected grid (NIG) area of Cameroon covering the Far North, North and Adamawa regions, access to electricity is lacking behind, with rural and urban rates estimated at more than three times lower than national averages. In these regions where more than seven million people live (Kenfack et al., 2011) the quantity of electricity delivered and the quality of the electric current have been poor so far. The electricity supply through the NIG area has remained the same for the last three decades, with an available capacity of 93 MW.

More so, access to electricity is achieved through grid extension only with constant power outage which has led to electric rationing in the area for the past three years now (Kidmo et al., 2021). In the Northern interconnected grid area, the vast majority of well-dispersed households have no access to electricity due to low incomes, coupled with high grid-connected costs by world standards. Additionally, a very high rate of grid losses makes grid extension not a cost-effective option for ENEO, the national transmission and Distribution Company. To cope with the growth of electricity demand, the Government of Cameroon has prepared a 2030 Electricity Sector Development Plan. This plan endorses hydropower and thermal power plants as the major sources of electricity generation for achieving sustainable economic development of the Country for the timeframe to 2030. Other renewable energy sources such as solar, wind and biomass are undermined in the plan. The NIG area receives average solar irradiation of 5.67 $kWh/m^2/d$ (meteornome) and can be considered the best alternative to reasonably provide immediate responses for the current imbalance between electricity demand and supply, in addition, to fundamentally contribute to reduce grid losses and outperform costly thermal power stations.

Furthermore, solar energy possesses advantages such as non-polluting, readily available, environmentally friendly and ease of installation which can be efficiently trapped to help achieve this goal. As such, this research work will provide answers to the potential of building photovoltaic power plant for the Garoua city council in a bid to meet up with the energy demand of the population.

Garoua, although a home to a 72 MW hydroelectric power plant, still witnessed very low rate of electrification with daily load shedding in the main towns and partially or complete non electrification in the villages (Godwe et al., 2021). This makes villagers in the rural area to walked great distances daily just to have their phones charged and to purchase fuels for lightening in the evenings. This region receives an average solar irradiation of 5.6 $kWh/m^2/d$. Despite these potentials, the Garoua city has not yet taken advantage to generate in a sustainable manner, electricity from solar energy to meet the electricity requirements of the municipality. A first step towards such a project is to carry out concrete technical studies to make sure that it does not fail or it is not designed with a lot of errors. To the best of our knowledge, such elaborate studies from an academic point of view that encompasses most of the required components for electricity generation are limited.

Objective

The main objective of this thesis is to show that electricity generation from solar radiation can be an alternative and environmentally friendly solution to reduce the electric power deficiency of Garoua city councils thereby boosting socio-economic development of the city.

More specifically this work seeks to:

- Determine the energy demand of the population,
- Size and cost equipment necessary for the generation of electricity from solar energy.
- Evaluate the environmental benefits of such a project.

To achieve the above-mentioned objectives, the major question asked was

"How can solar energy be valorized so as to meet the needs of the population?"

To these effects, the following hypothesis were fixed:

Solar energy can provide sufficient, affordable and clean energy to the Garoua community.

Importance of the study

The world's demand for energy is rising due to an expansion of the economy and also an increase in population. There is therefore reason to believe that there will be further increase in the demand than supply since the world common energy sources (fossil fuels) are gradually running out. Aside from energy insufficient problems and constant outages especially in less developed countries, renewable energy is a better option because the constant rise in the amount of CO_2 produced yearly from using coal and fossil fuels (according to the Global Energy and

CO_2 Status Report) resulted in a third of the total global CO_2 emission. Additionally, renewable energy saves cost, reduces electricity tariffs and have a payback period much lesser than plant life span.

The importance of this work is to provide an engineering-based proposal to help address the deficit in electricity generation in Cameroon and particularly in the Garoua council city. The proposal seeks to provide an advantageous methodology for electric power generation; a photovoltaic power plant. With the implementation of this proposal, cheap, efficient and reliable electric power will be provided to thousands of households in Garoua.

CHAPTER 1. LITTERATURE REVIEW

1.1. DEFINITION OF KEYWORDS AND CONCEPTS

1.1.1. NON-RENEWABLE ENERGY

These are energy sources which take a very long period of time to be replenished. They get squeezed and cooked by the Earth's inner pressure and heat. Fossil fuels supply about 80-90 percent of the world's energy (Klaus et al, 2014) and are also responsible for a third of CO_2 emissions. They include fossil fuels; oil, coal, natural gas and nuclear energy as showed in **figure 1.1.** There are formed over hundreds of millions of years when plants and sea creatures rot away, fossilize, and then get buried under the ground. It is worth noting that their use is faster than the use of natural energy sources, which made it more reliable than renewable energy sources.

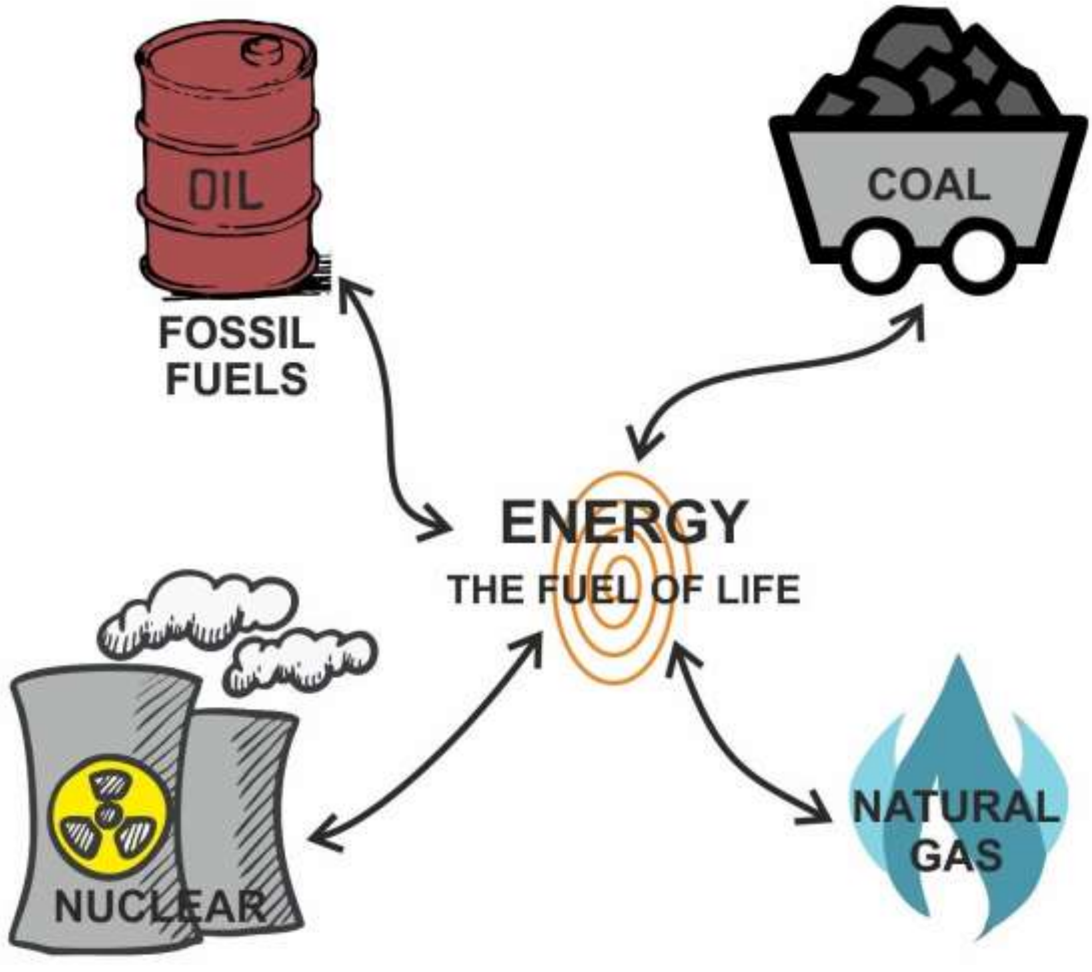

Figure 1.1. Non-renewable Energy sources

(Energy. Port, July 2022).

Natural gas

Natural gas is often made up of methane, and is found near other fossil fuels, such as coal, produced by methane generation in landfills and marshlands. When it burns, it produces half of the greenhouse gas emissions.

Coal

Coal is a sedimentary rock produced in marshes, where organic matter accumulates from plants, and the aggregation of these materials forms a substance known as peat, which releases volatile components, such as water and methane, resulting from the pressure from peat, and then coal is produced. Coal is also the most widely used fossil fuel in the world to produce electricity. In the United States, about 93 % of coal consumed is used to generate electricity, and coal combustion produces almost three times the amount of CO_2 emissions.

Nuclear energy

Nuclear energy is emitted at nuclear fission, the split of the nucleus of an atom. Nuclear power is a common method of generating electricity worldwide. Although it is a common mineral found in rocks around the world, nuclear energy has many disadvantages, such as the production of radioactive materials. Radioactive waste can be highly toxic and they also increase the risk of blood disease, cancer and bone caries among people at risk.

petroleum

Petroleum or crude oil is defined as a toxic flammable liquid that occurs in geological formations underground, used as fuel oil and gasoline, but is likely to be present in the components of medicines, plastics, and kerosene.

1.1.2. RENEWABLE ENERGY(RE)

In line with the International Energy Agency (IEA) renewable energy resources are “derived from natural processes” and “replenished at a faster rate than they are consumed”. These energy sources include solar, biomass, wind, tide, and geothermal. There produce very little emissions of CO_2 and are therefore environmentally friendly.

Renewable energy sources as presented in **figure 1.2** are virtually inexhaustible, non-depletable and most often refer to as nonconventional sources. The most important characteristics of renewable energy (Toklu, 2013) are:

- A clean and environmentally friendly energy,
- Does not leave Harmful gases, such as carbon dioxide,
- Does not adversely affect the surrounding environment and
- Does not play a significant role in temperature levels.

These sources of energy are in stark contrast to non-renewable sources such as natural gas and nuclear fuel which lead to global warming and the release of greenhouse gases.

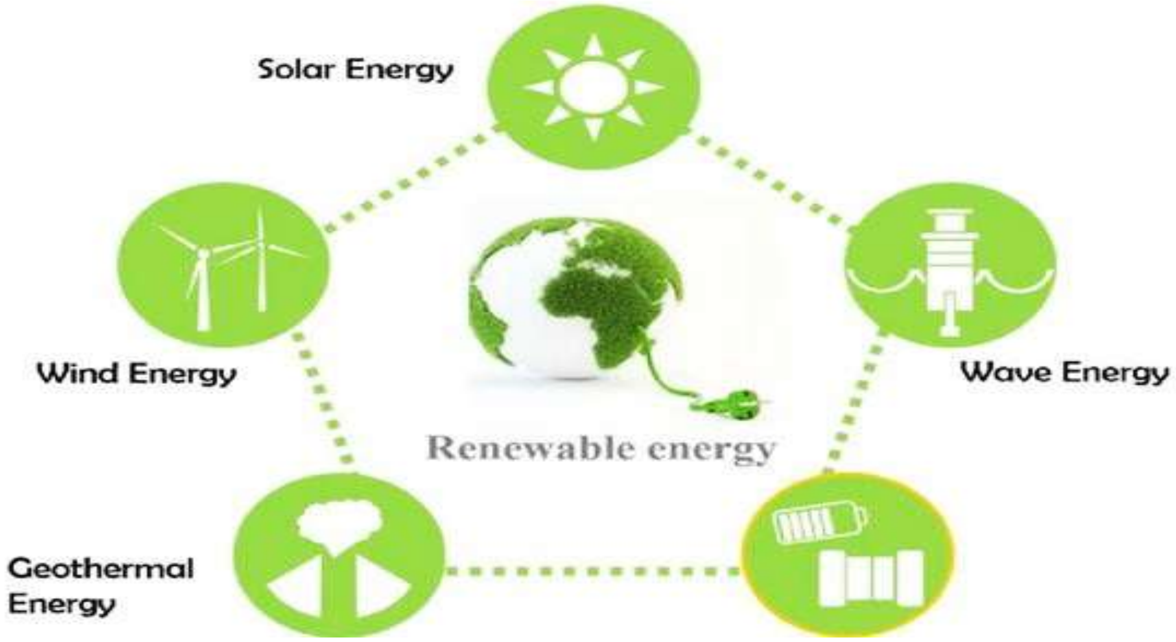

Figure 1.2. Renewable energy sources

(Myounghoon, 2016)

1.1.2.1. Advantages of renewable energy

There are number of advantages renewable energy has which makes it a distinct source of energy. These advantages amongst others include:

- They are clean and environmentally friendly since the emit minimum carbon dioxide and greenhouse gas to the environment.
- By reducing greenhouse gas emissions, RE turns to improve Public Health issues related to pollution.
- They exist abundantly and can easily be renewed in lesser time frame.

- There are very economical.
- RE helps in the mitigation of gaseous effects and thermal emissions.
- It uses uncomplicated technologies and can be manufactured locally in developing countries.

1.1.2.2. Renewable energy sources

As earlier mentioned above, renewable energy can be obtained from several types and can be divided into different categories:

Solar energy

Solar energy is the most readily available form of energy. The radiant light from the sun and the heat are harnessed using technologies like photovoltaic, solar heating, thermal energy and artificial photosynthesis. It is the most important of the non-conventional sources of energy and depending on the way they convert it into solar power, its technologies are characterized as either active or passive. There are huge benefits in developing inexhaustible, affordable and clean solar energy technologies. Solar energy as an inexhaustible, indigenous and mostly import-independent resource has several advantages. These include enhanced sustainability, reduced pollution, and lowered costs of mitigating global warming and fossil fuels (Sarah et al., 2020).

Wind Energy

This refers to harnessing the wind to provide the mechanical power through wind turbines to turn electric generators. Wind energy is produced when wind turbines convert mechanical energy through the movement of the wind into electrical energy by turning a turbine which is coupled to a generator. It is one of the cleanest sources of energy, as it does not lead to global warming, and is always abundant (Argawal et al, 2020). Approximately 2 % of the sunlight failing on the earth surface is converted into wind energy and this form of energy is enormous overflowing the worlds need for energy consumption in any given year. The turbines come with two or three blades which are fixed onto a shaft to form a rotor. The turbine catches the wind as it blows, and thus pulls the blade towards it which causes the rotor in turn to lift it. The lifting force being greater than the wind's force on the front side will result in a drag. The lift and drag in collaboration then force the rotor to turn. The rotor, coupled to a shaft which is found inside a generator, produces electricity. It can be used for pumping water, powering industries, lighting in the home and a great deal of other things.

Bioenergy

Bioenergy is derived from the so-called biomass, which is an organic substance that stores solar radiation and then converts it into chemical energy. These sources may be wood, fertilizer, or sugar cane, and the sources of bioenergy are similar to fossil fuels.

Hydropower

Hydroelectric is a comprehensive term for both electricity and water. This type of energy is used to exploit hydropower to generate electricity. In the process of exploiting this energy, the energy in the water, or the energy of the situation, is completely relied upon and converted into kinetic energy through the fall and flow of water from top to bottom

1.1.3. SUSTAINABILITY

Sustainable development is humanity’s ability to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. It is the ability to sustain finite resources necessary to provide for the needs of future generations of life on the planet, it designs activities to meet human needs while preserving the life support systems of the planet. Sustainability is supported by three key pillars: economic, environmental, and social. It’s worth noting that thought it wise to include a fourth pillar called Cultural integrity which could be used in the African context of seeking sustainability by including their cultural diversities and beliefs into developmental goals.

1.2. SOLAR ENERGY AND ITS APPLICATION

1.2.1. SOLAR ENERGY

The Sun also refer to as the core of the solar system, is the closest star to Earth, estimated at 26,000 light-years. The star is estimated to be 4.5 billion years old. The massive gravity in the Sun is responsible for the stability of the solar system so that all components of the solar system are fixed from large planets too small parts of each Orbit.

Solar energy, the energy emitted by the sun's rays, is mainly in the form of heat and light, is the product of nuclear reactions within the star closest to us, the Sun. This energy is of great importance to the earth and the organisms on its surface. The amount of this energy produced far exceeds the current energy requirements in the world in general, and if properly harnessed and exploited may meet all future energy needs.

This solar energy reaches the universe through electromagnetic waves. These waves are differentiated by their spectrum which is the length of the frequency of the waves. The length or range of the spectrum determines the magnitude of energy it possesses; a Spectrum with a shorter wavelength has more energy than spectrums with a longer wavelength. On the earth's surface, only wavelengths ranging from 0.29 µm to 2.3 µm can be detected (Van Niekerk and Hall, 2013). The spectral distribution of solar radiation at the level of the earth's surface is represented by **Figure 1.3.**

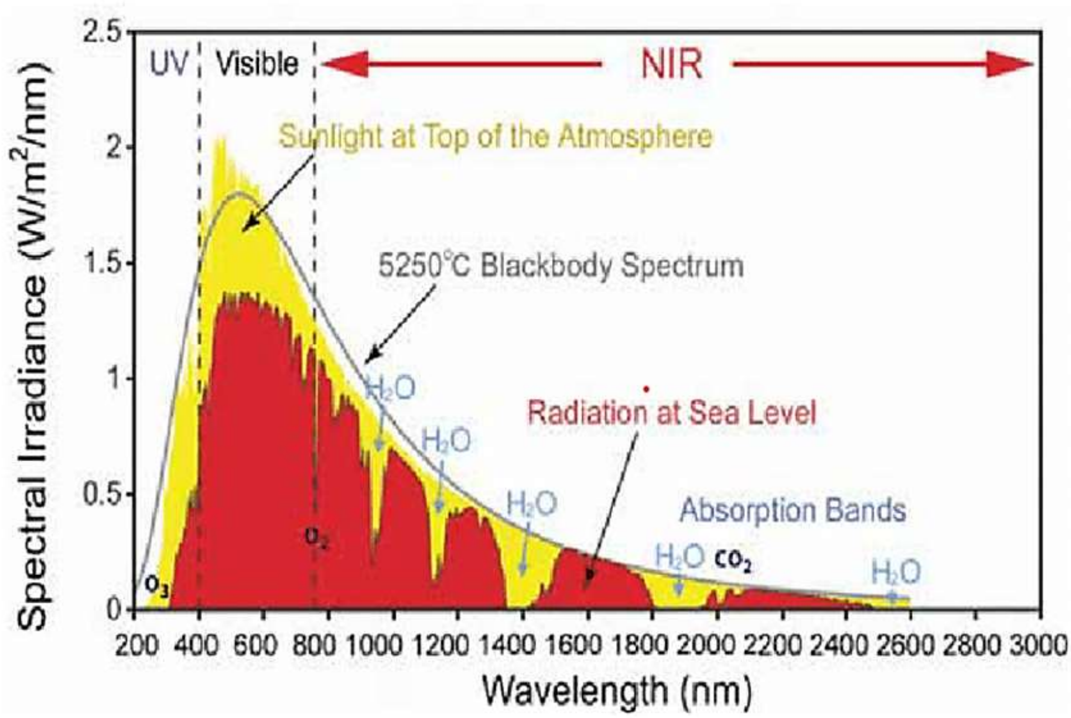

Figure 1.3. Spectrum of solar radiation on the earth surface

(Beckmann et al, 1963).

The energy associated with this solar radiation is distributed as follows;

- 9 % in ultraviolet range (< 0,4 µm);
- 47 % in visible range (0,4 à 0,8 µm) ;
- 44 % in infrared range (> 0,8 µm).

As the sun's rays pass through the atmosphere, solar radiation is absorbed and scattered. According to (Pinho J. and Galdino M., 2014), the radiation components described are:

- **Extraterrestrial irradiance**: Solar irradiance that reaches the top of the Earth's atmospheric layer.

- **Beam irradiation**: Solar irradiation that focuses directly on the surface without any influence.
- **Diffuse irradiation**: Solar irradiation that reaches the surface after being scattered throughout the earth's atmosphere.
- **Reflected irradiation (albedo)**: irradiation reflected by the surrounding environment (soil, vegetation, obstacles, rocky terrain,).
- **Global irradiation**: the amount of irradiation resulting from the sum of direct, diffuse, and albedo solar irradiations.

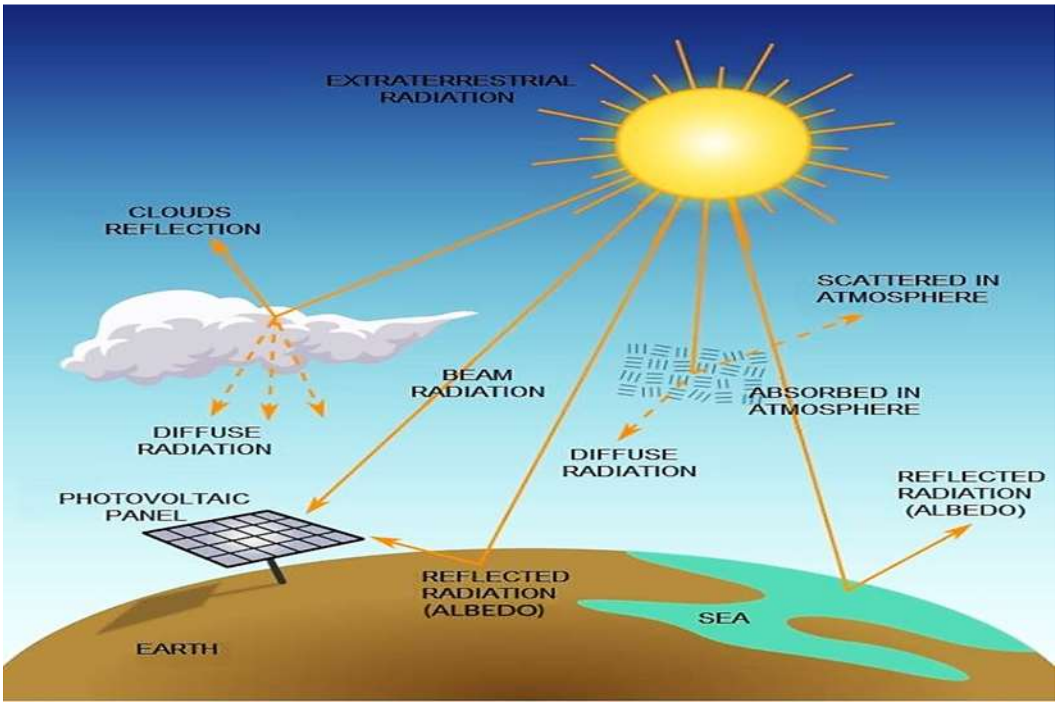

Figure 1.4. Solar radiation components

(Muriele Souza 2019).

1.2.1.1. Advantages of solar energy

Solar energy is the most abundant and freest source of energy used by human beings in its day-to-day activities. This form of energy exhibits the following advantages:

- Costs for homeowners and real estate can be reduced by using solar energy.
- Many jobs are available due to the increase in companies in the renewable energy sector.
- Solar plants are environmentally friendly compared to nuclear power plants, by reducing emissions of harmful chemicals to the environment.

- Excess energy can be stored and distributed in months that do not receive much sunlight.
- It has the potential to innovate and develop compared to the methods of producing energy from other sources.
- Cars can use solar energy instead of fuel, eliminating the need for oil.

1.2.1.2. Disadvantages of solar energy

Despite its numerous conveniences both to human and the environments, there exist a few limitations to the use of solar energy:

- The large cost of solar panels to produce large amounts of energy.
- Recycling solar panels is considered to be a cause of water pollution, as this negativity can be avoided if organic materials are used in the manufacture of solar panels.
- Relying on battery systems during the night and times when panels cannot absorb enough solar radiation.
- Solar energy systems take time to become mainstream and widely accepted as an alternative to energy production.

1.2.2. APPLICATIONS OF SOLAR ENERGY

Solar energy can be converted into electrical energy and thermal energy through photovoltaic conversion and thermal conversion of solar energy as follows (Greeley, 1979; Foster et al., 2010).

1.2.2.1. Solar Thermal Applications

This form of energy conversion produces heat from infrared solar radiation to heat water or air. It is applicable in solar water heating, solar cooking and sewage treatments.

Solar cooking.

The solar cooker is a device that uses sunlight to cook, dry and pasteurize. For example**, Figure 1.5** shows the parabolic solar cooker.

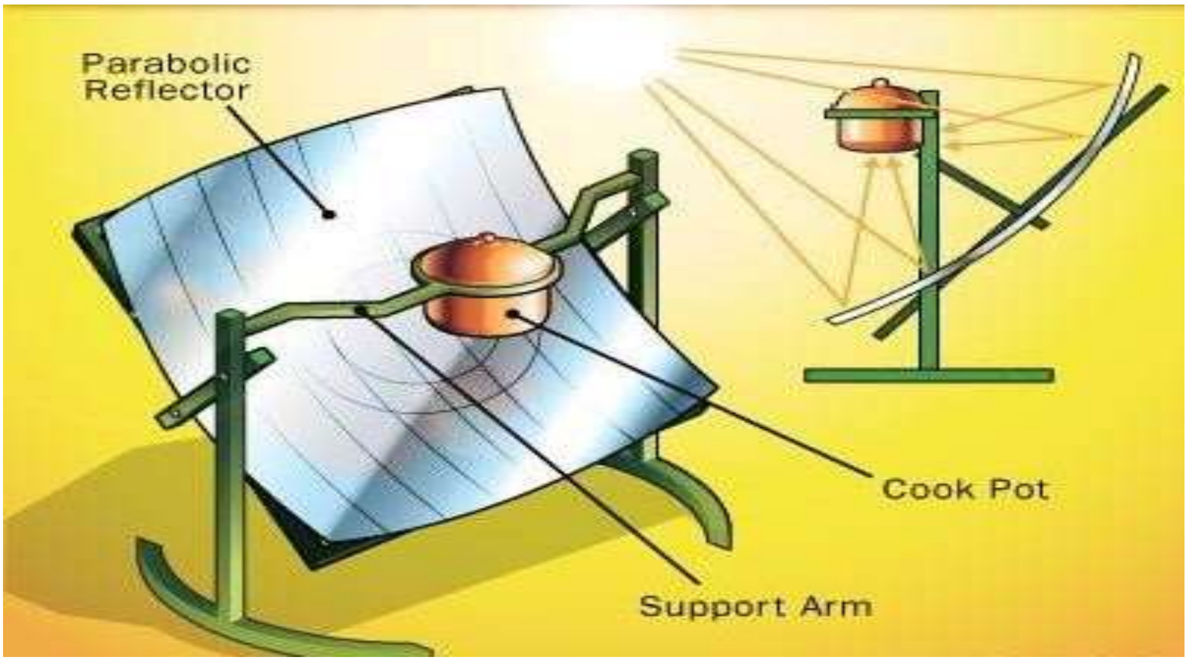

Figure 1.5. Parabolic solar cookers

(Madhav solar water heater, 2018)

Solar water heating

It is an integrated system consisting of several parts used to collect the solar radiation falling on them and converted into heat energy to be used to heat water during the hours of sunshine where hot water is stored in a heated tank for use during the day as shown in **Figure 1.6.**

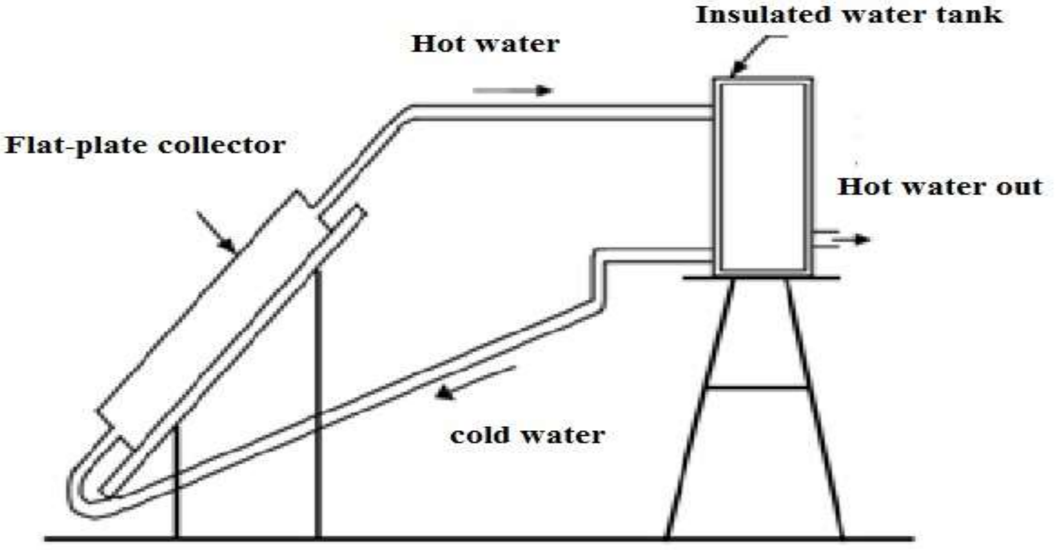

Figure 1.6. Solar water heating

(World academia of science 2014)

Sewage treatment

Solar energy is also used to remove toxins from contaminated water using photo degradation.

1.2.2.2. Use of Solar Energy to Generates Electricity

Electricity is one of the energy carriers that can be used for many purposes. Solar energy can be converted into electrical energy through photovoltaic conversion. It is intended to convert solar or light radiation directly into electrical energy using photovoltaic solar cells as shown in **Figure 1.7.**

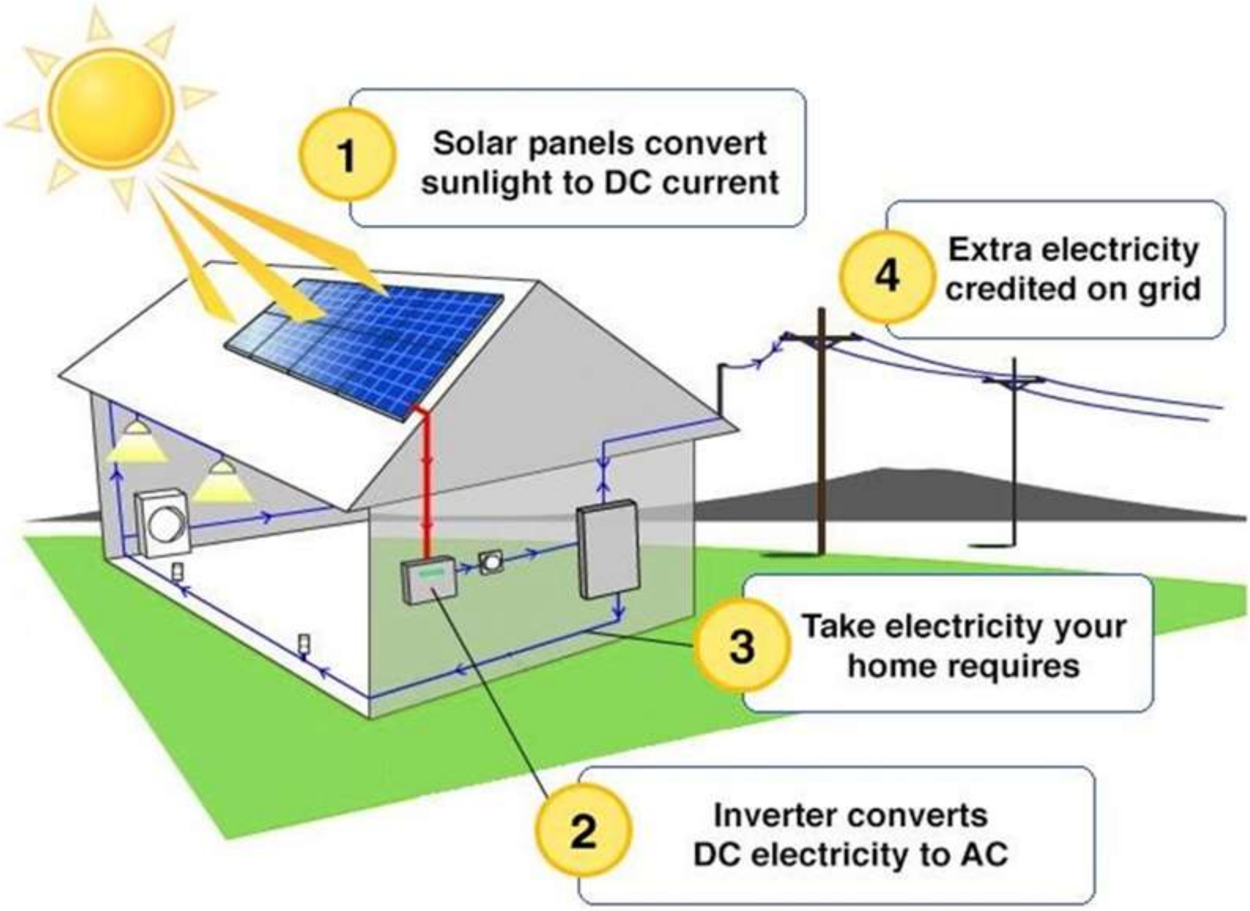

Figure 1.7. Use of Solar energy to generate electricity

(averer.com2012)

1.3. PHOTOVOLTAIC

With the increasing interest in renewable energies in general and solar energy in particular, there have been attempts to provide solar energy technologies with an amount of energy equal to or close to the amount of energy spent (Chel and Kaushik, 2018). It has become popular, transforming buildings from energy-consuming plants into productive buildings that rely on the sun as an economical source of energy, and are commonly used in areas with high levels of solar radiation and even areas characterized by short hours of sunshine. The solar system for electricity generation relies on four basic elements as fellow **(see figure 1.8):**

- Solar panels
- Battery
- Invertors
- Charger controllers

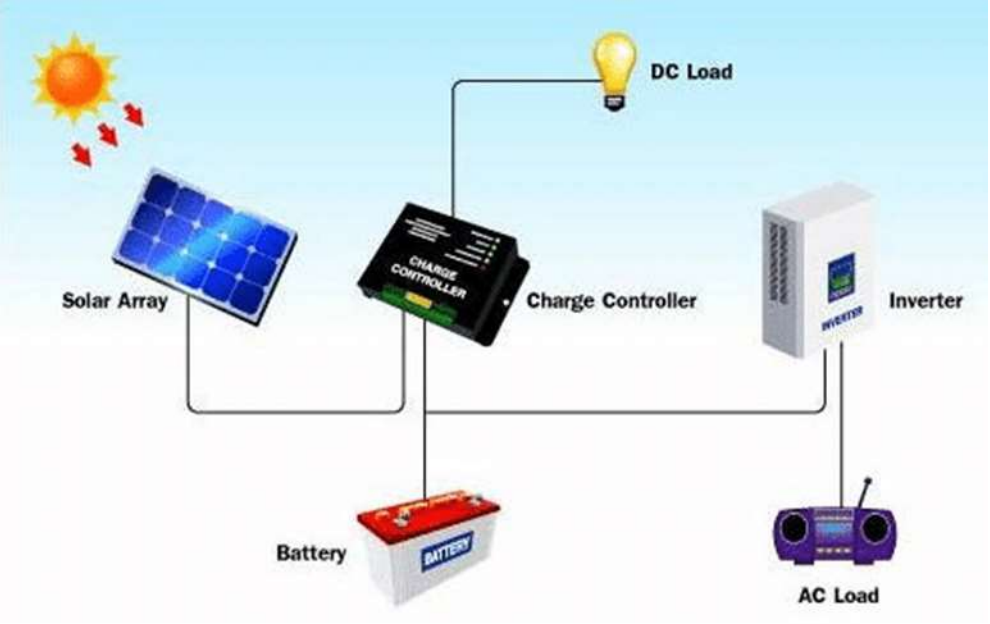

Figure 1.8. Elements of PV system

(Basic of solar cell, Solar Photovoltaic modules-leonics)

Solar panel

The solar panel is the main device which respond directly and indirectly to solar radiation by converting radiation energy to electrical energy. The components of solar panels are shown in in **Figure 1.9.** The solar panel is solar cells grouped together to produce direct current (DC) electricity that can be used to operate some equipment or stored in batteries recharged, which more than once. The unit of the measured power of the cell is Watt.

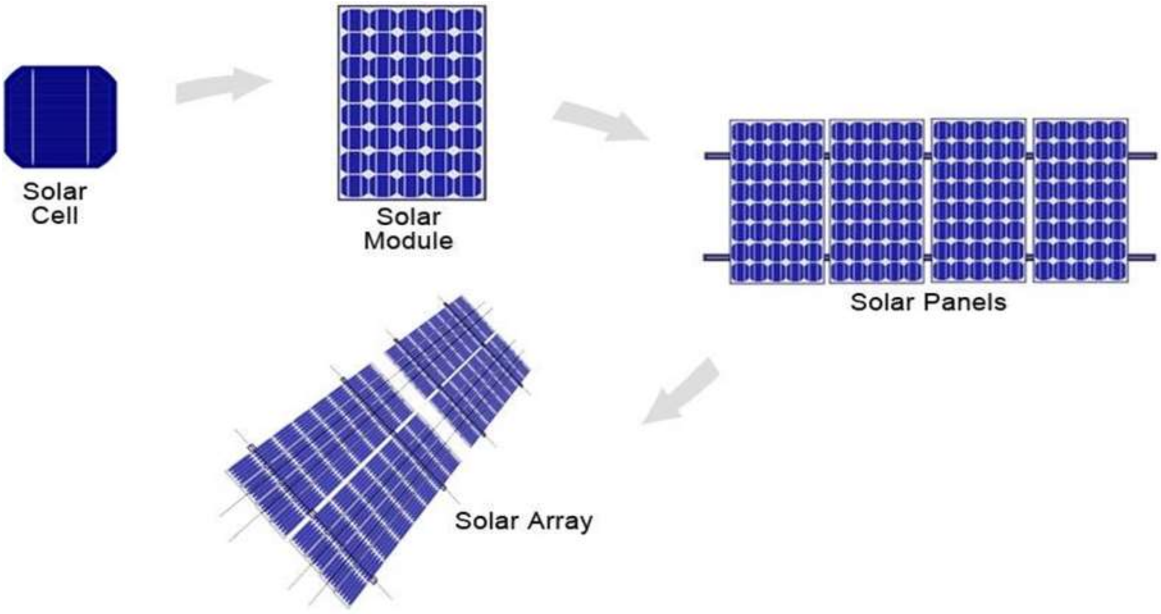

Figure 1.9. Elements of PV panel

(Basic of solar cell, Solar Photovoltaic modules-leonics)

Charger controller

The charge controller (also known as a voltage regulator) is the intermediary device between the panels and other PV system components such storage unit and inverter. Its purpose is to control the power flow between these components thereby protecting them. The basic function of a charge controller is to regulate battery voltage.

Inverter

The power produced by the panels is DC, therefore the inverter changes direct current (DC) to alternating current (AC) making it suitable to be used by most home appliances.

Storage unit/Batteries

The storage unit is composed of batteries; its function is to store excess electric power. These batteries are classified as deep cycle batteries; they can withstand continuous charging and discharging. They are different from car/vehicle batteries

1.3.1. FUNCTIONING OF PHOTOVOLTAIC CELLS

The word Photovoltaic can be broken down into two parts; photo and voltaic which means light and voltage respectively. Photovoltaic signifies electric voltage caused by sunlight. Essentially, sunlight is composed of photons, which can be considered discrete units of the energy stored in light. A PV cell is made from semiconductor materials with a P-N junction diode. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor with a few finer electrodes on the top of the p-type semiconductor layer. These electrodes do not obstruct light from reaching the thin p-type layer. The p-n junction is just below the p-type layer. A current collecting electrode is also provided at the bottom of the n-type layer and the entire assembly is encapsulated by a thin glass to protect the solar cell from mechanical shock. This is illustrated in **Figure 1.10**.

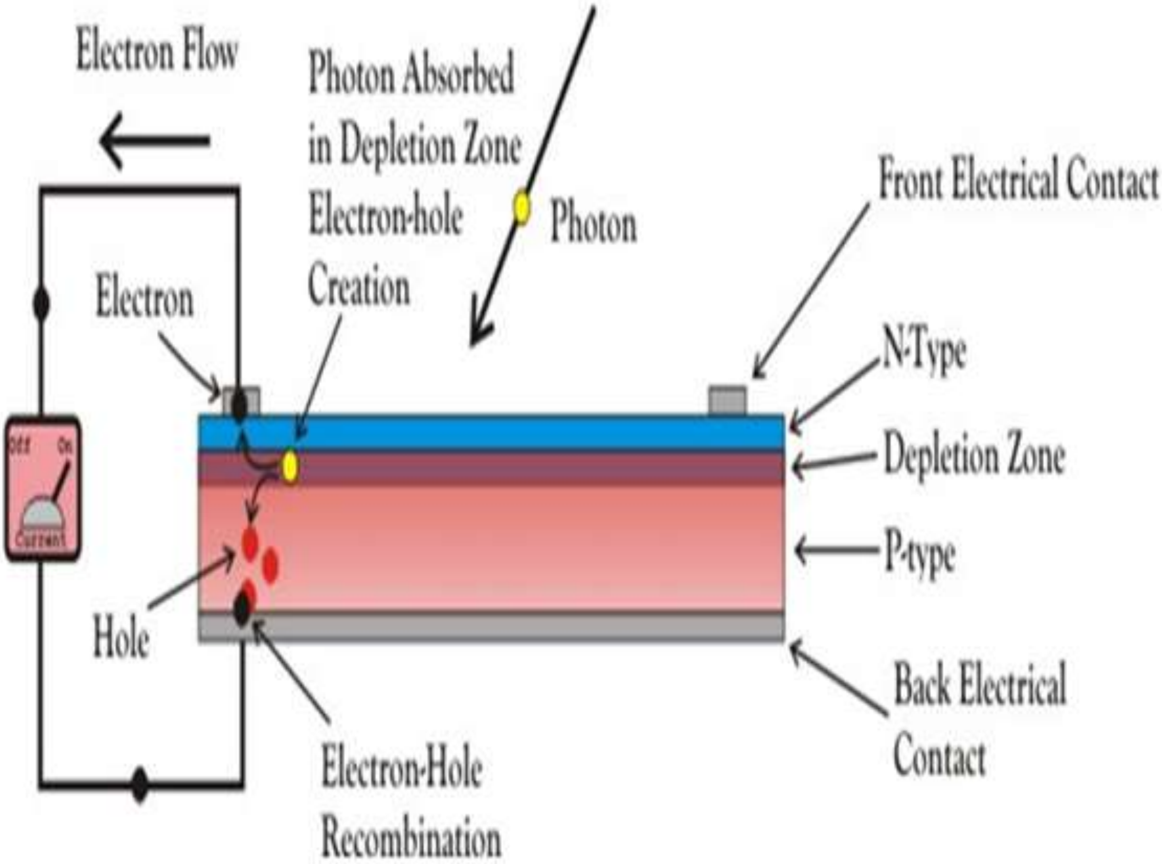

Figure 1.10. Construction of solar cell

(https://www.electrical4u.com/solar-cell/)

WORKING PRINCIPLE OF SOLAR CELLS

The working principle of a solar cell is based on the well-known photovoltaic effect discovered by the French physicist Alexander Becquerel in 1839. This effect generates an electric field at the junction of two materials in response to electromagnetic radiation (photons). It is worth noting that the PV effect is closely related to the photoelectric effect which was explained by

Albert Einstein in 1905. He assumed that photons are quantum energy which is present in light, and this energy is given by the following expression,

$$E=h.V \qquad 1.1$$

Where h is Planck's constant and v is the frequency of the light. This scientific explanation granted Einstein the Nobel Prize in Physics in 1921. Accordingly, the photovoltaic effect takes place in a solar cell, a structure based on two types of semiconductor materials that are joined together to create a p-n junction diode that operates under solar illumination as in **Figure 1.11**

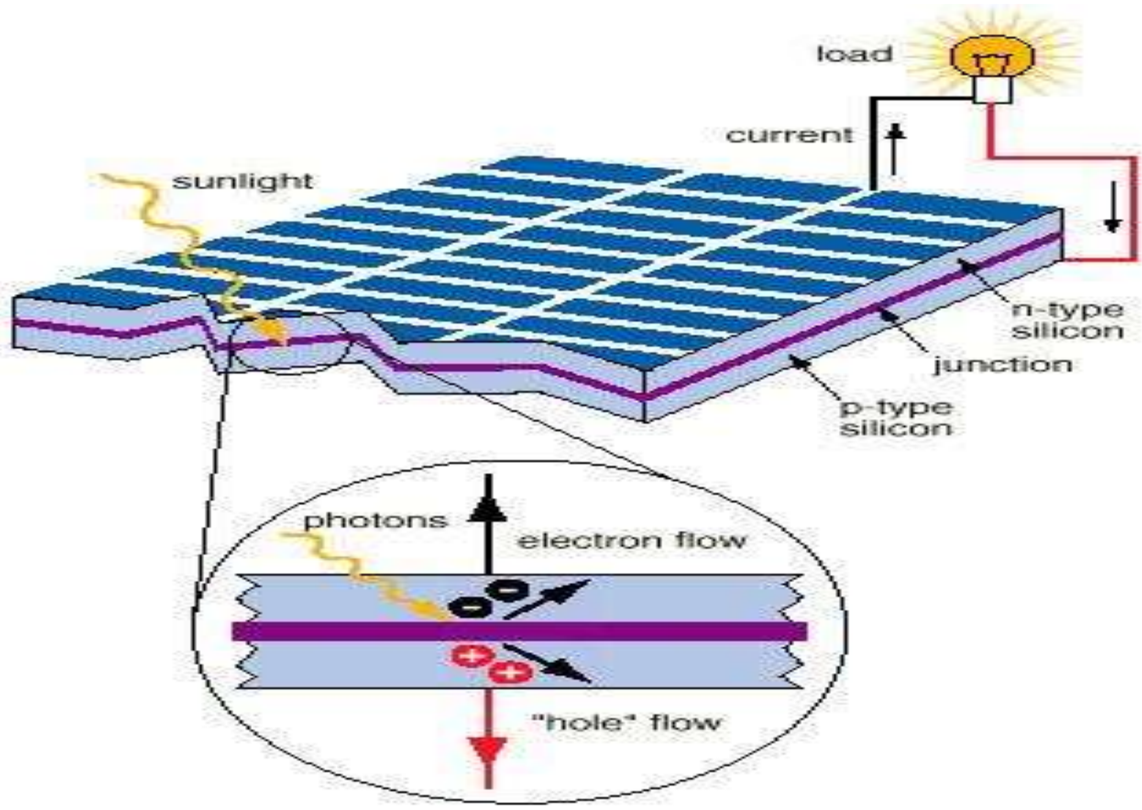

Figure 1.11. Basic operating principle of a solar cell (https://www.apogeeweb.net/article/27.html)

Essentially, the PV effect is described by three basic processes:

- **Generation of charge carriers (electron-hole pair) due to the absorption of light.** When sunlight hits the semiconductor surface, a portion of photons is transmitted and, then, absorbed into the material producing photo-generated electron-hole pair; while the rest is reflected.
- **Separation of the photo-generated charge carriers in the junction.** The electron-hole pair is separated by the internal built-in electric field of the p-n junction before they recombine.

- **Collection of the photo-generated charge carriers at the terminals of the junction.** The charge carriers are extracted from the solar cell with electrical contacts, thus contributing to the output current in the external circuit. Finally, the chemical energy of the charge carriers is converted to electric energy. At this point, as electrons have passed through the circuit, they will recombine with holes at a metal absorber interface.

1.3.2. TECHNOLOGIES OF SOLAR CELLS

There are various PV cell technologies in the market even though they all perform the same task of harvesting solar energy and converting it to useful electricity. There exist 3 basic generations of PV cells and are classified as shown in **Figure 1.12**. The first-generation solar cells dominate 80 % of the world markets today (Chowdhury et al., 2020) and are manufactured from silicon based materials. This is detailly explained in this work.

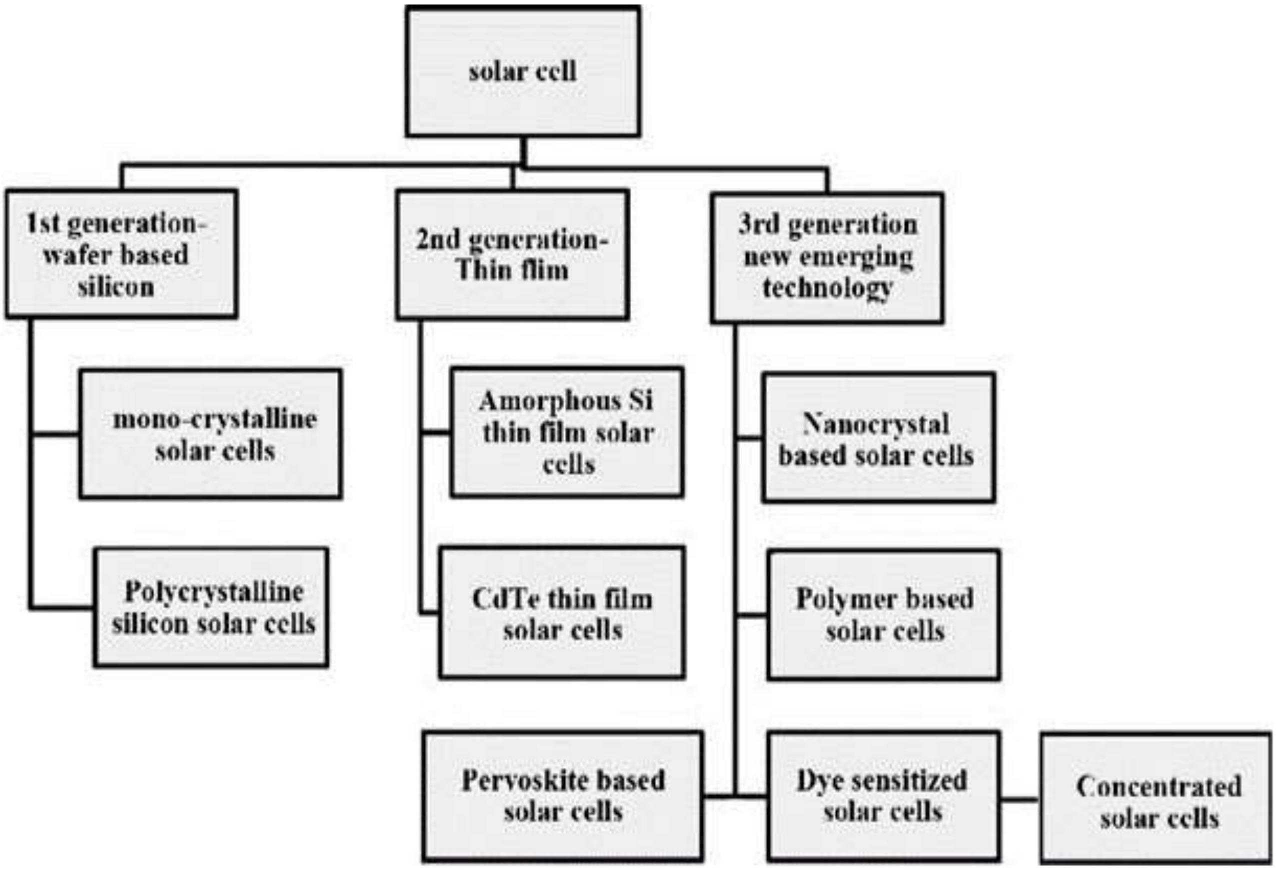

Figure 1.12. Classification of PV cells technology

1.3.2.1. Monocrystalline

It is made from pure monocrystalline silicon that has a single, continuous, crystal lattice structure with little or no impurities made from single silicon crystals as showed in **Figure 1.13.** They are characterized by black PV cells with rounded edges and have a high conversion efficiency of up to 26.7 % (Sarah et al., 2020). They are more productive per square meter, especially for limited space. These types of PV cells are the most efficient with a long-life span and low installation cost. They, however, have some setbacks as they are fragile and the cost of production is high coupled with the fact that much silicon is used up during the production process.

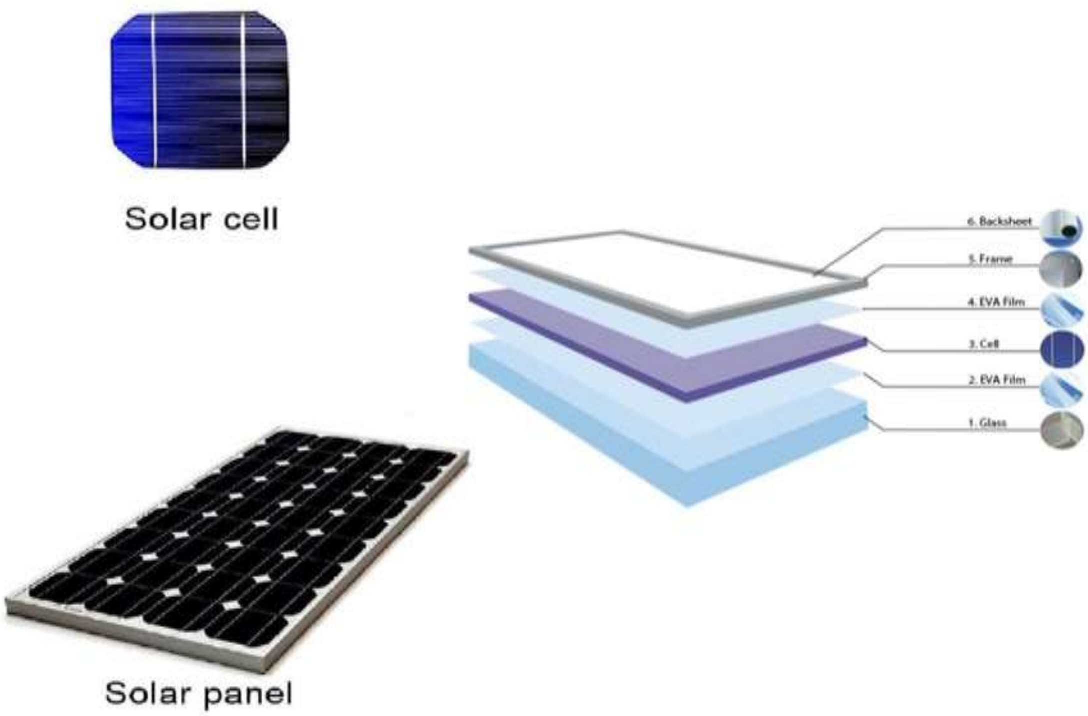

Figure 1.13. Monocrystalline solar panels

(https://www.oorjan.com/blog/2018/04/30/different-types-solar-panels/)

1.3.2.2. Polycrystalline

Polycrystalline silicon cells have other names such as polysilicon, and multi-crystalline line since they are made from numerous monocrystalline cells as in **figure 1.14.** There are characterized by blue-hued PV cells with straight edges. They have a lower efficiency of 22.3 % (Sarah et al., 2020) compared with monocrystalline cells. Their production process is simple and there has a more heat tolerant than silicon-based panels. As inconvenient, there have a lower conversion and lower space efficiency.

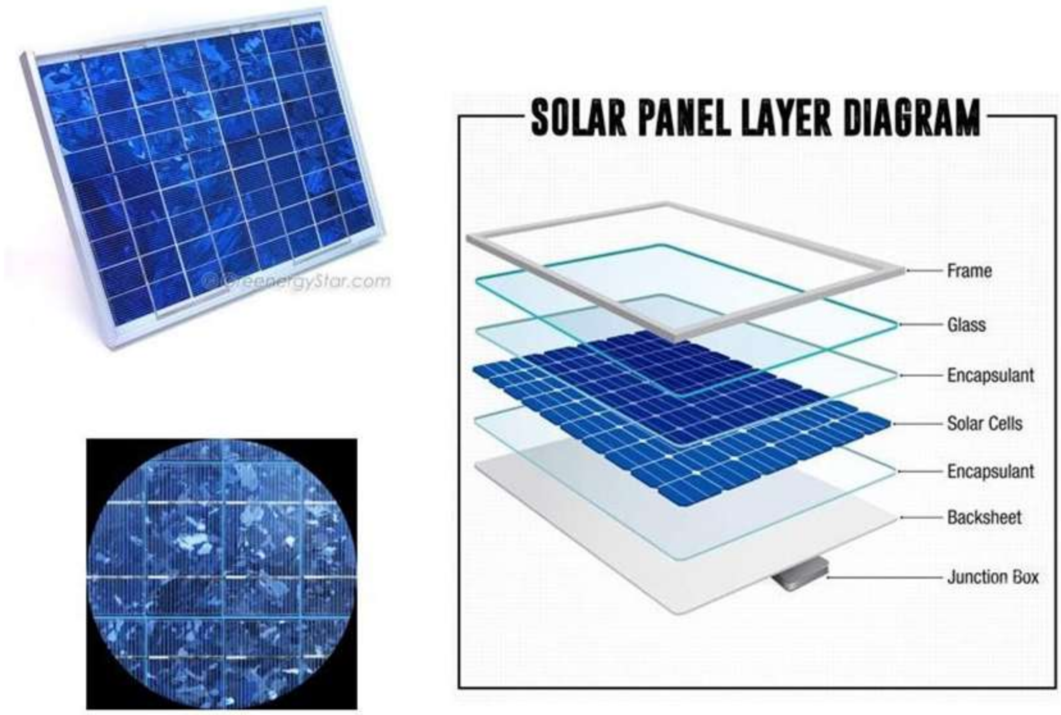

Figure 1.14. Polycrystalline solar pane

(https://www.oorjan.com/blog/2018/04/30/different-types-solar-panels/)

1.3.2.3. Thin film technology

This is the third type of first-generation solar panel as describe in **Figure 1.15**. This type is flexible and easy to install. It is produced by depositing one or more thin layers of photovoltaic material on a substrate. Large-scale production is simple and cheaper as compared to crystalline-based solar cells but occupies larger space as they are moderately efficient. The performance degrades faster than mono- and polycrystalline solar panels. This may be the reason why they come with a shorter warranty period. The homogenous appearance makes them look more appealing good. Higher temperatures and shading have less impact on solar panel performance. The present market for thin-film PV is grown about 55- 60 % annual over the past 10 years (Hudedmani et al., 2017).

Figure 1.15. Thin-film solar panel

(https://www.oorjan.com/blog/2018/04/30/different-types-solar-panels/)

1.3.3. FACTORS WHICH AFFECT SOLAR RADIATION

Solar radiation is the actual fuel for all solar energy systems, so the efficiency of solar panels producing electricity as well as thermal systems producing hot water depends on the availability and density of solar radiation. The radiation above the atmosphere is relatively constant, but the amount reaching the surface of the Earth varies very differently. In fact, there are many factors; however, according to (Krzyścin and Jarosławski, 1997) the most important factors affecting the quality of solar radiation falling and thus the efficiency of the productivity of solar panels are:

1.3.3.1. Geographical location

Due to the spherical nature of the Earth, the rays falling on the surface are more intense and stronger as we get closer to the equator and because it is the shortest way of radiation to reach the surface perpendicular and thus the radiation lost due to collision with the atmosphere less. If we move away from the equator north or south, it will increase the period of fusion between radiation and the envelope, causing dispersion and thus weaken the intensity and strength of radiation.

1.3.3.2. Suspended particles

Normally, the Earth's atmosphere has suspended particles of dust or products of human industrial activity and pollution, and the quantities and concentration of these bolds vary depending on the place and time of year. Its importance for solar radiation is that it filters and reduces radiation. While this affects the performance of solar panels, it is more detrimental to the performance of the radiation concentrates used in giant solar systems.

1.4. PHOTOVOLTAIC PV SYSTEM

A PV system contains many different components which include the PV modules or solar panels, DC-DC converters which are used to convert the module output, Inverters or DC-AC converters which are used in grid connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid (Klaus et al, 2014). Also, cables are used to connect the different components of the PV system with each other and to the electrical load. It is important to choose cables of sufficient thickness in order to minimize resistive losses. Although not directly a part of the PV System, there is the electric load. These are all the electrical appliances that are connected to it. They have to be taken into account during the planning phase, as well as whether they are AC or DC loads. When for example a whole house needs to be powered, the system must be operational day and night. It may need to feed both AC and DC loads, have reserve power and may even include a back-up generator. Depending on the system configuration, three main types of PV systems are seen: stand-alone, grid-connected, and hybrid systems.

1.4.1. GRID-CONNECTED SYSTEMS

This is a solar power system that is linked to the utility grid. In unconnected systems (standalone systems) a battery bank is needed for energy storage but in grid-connected systems, the energy which is produced more than the requirement of the end user is transported back to the utility grid to be used where there is a shortage of energy. In grid-connected systems, the community electricity grid is used as an energy store as well. Many countries around the world prefer mostly solar PV systems to be connected to the utility grid because that helps their national grids are getting access to energy from the solar systems, reduces the production of cost of energy production by use of fossil fuels and in return the citizens with solar installations enjoy rebates.

1.4.2. STANDALONE SYSTEMS

The other term used for this kind of system is 'off-grid solar power system' as there are commonly used in areas where the grid or utility is not available. These systems are independent of any other source of energy and the energy produced by the sun is not only utilized during the day but access is stored in battery banks to be used when there is no sun available as shown in **Figure 1.16**. These systems are used where a supply of electricity is immediately required and with a minimum price. The systems can be installed in the shortest periods and no hassle or rustle is needed like the provision of high transmission lines and transformers. These systems are mostly being used in rural electrification projects and in remote areas where the grid is not available. The OFF-Grid solution is the solution in which you can simply live without the GRID and produce and use your own produced energy according to your requirements. This system is use in for design and costing for this work.

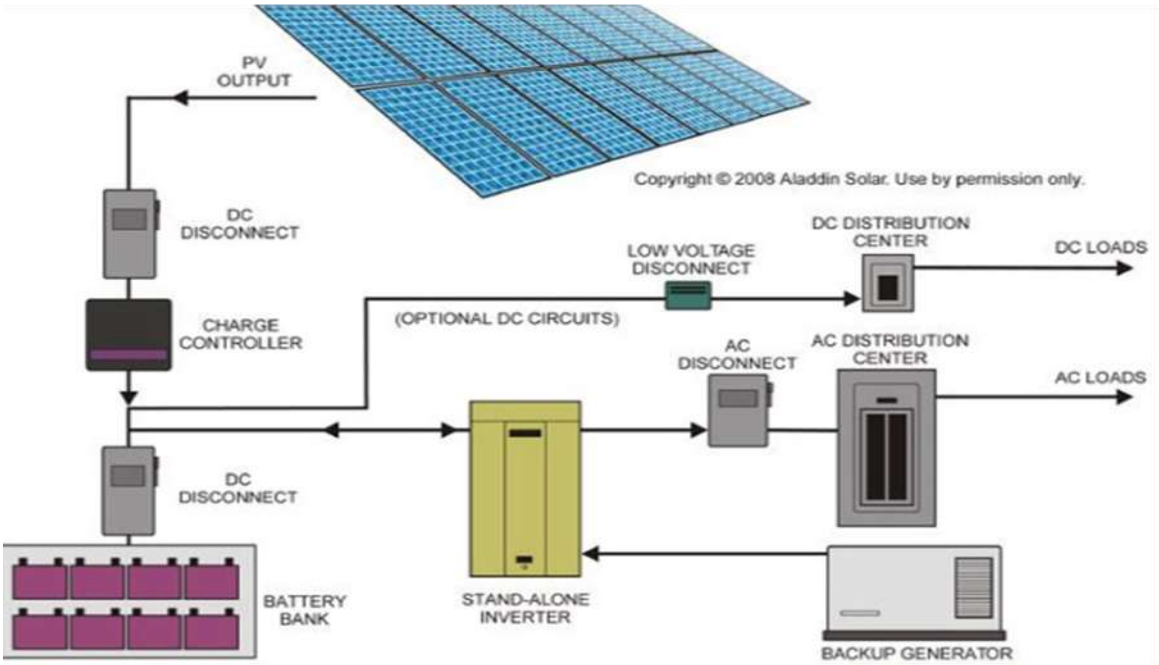

Figure 1.16. Stand-alone system

(Rabbani, 2021).

1.4.3. HYBRID SYSTEMS

In hybrid systems, the required output power is obtained by two or more different power generating sources. A system can be hybridized by combining different renewable energy sources such as solar and wind to get the common output required by the end user. The solar power systems can also be joined together with the diesel generator in areas where there is need and for better performance. The main aim of hybridization is to get a stable output from renewable energy sources and cater to fluctuations caused because of the environmental conditions while using solar and wind generation. Sometimes hybrid systems are also known as "Integrated renewable energy systems". Hybrid systems are generally planned to meet the peak demand when they run in combination with conventional power generation systems. For example, in the case of wind and PV hybrid power plants, these two separate systems share a single inverter for power conversion and a single storage facility depending upon the case of the grid-connected system (Rabbani, 2021).

1.5. CHALLENGES OF PV SYSTEMS

Solar PV technology is not without its flaws. There exist shortcomings that prevent it from achieving its full potential as a source of renewable energy and the challenges highlighted here are typical of the case of Cameroon and most developing countries of the world. They have been categorized in different sections as follows:

Financial challenges

- High initial expenditure of investment for non-conventional energy source is a hindrance for the development of this technology.
- Furthermore, developing nations like Cameroon depend on imported goods and technology from developed countries and it add extra cost to the existing power scenario.
- The cost of the new technology is not competitive enough to overtake conventional systems
- Lack of financial support or subsidy for energy production from RE sources.

Social-technical

- Geographical location is a primary factor as the PV systems are feasible only in particular areas where solar exposure is available.
- Lack of qualified professionals to train, operate and manage conventional energy structures especially in rural communities negatively affects the willingness to adopts these technologies due to fear of failure.
- Users fear this system not functioning during raining season and avoid using PV systems due to lack of knowledge. This lack of knowledge hinders the acceptance of the technology among both users and installers.

- Insufficient operation and maintenance of the auxiliary components and lower reliability of the technology reduces confidence among consumers to support and adopt non-conventional energy technology.
- Expensive means of energy storage in PV systems.
- No commercialization on large scale in RE generation.
- No local manufacturers of for efficient conversion of solar energy conversion equipment.

Policy

- No national strategy given to encourage solar energy production.
- Insufficient national policy frameworks to encourage the developments of non-conventional energy technologies as well as flaws in follow up program designs.
- Poor perception about the potential and commercial viability of RE as well as lack of awareness regarding the renewable energy consumption

1.6. ENERGY SITUATION IN CAMEROON

Cameroon has a great potential of both renewable and non-renewable energy resources such as hydropower, wind, oil, biomass, solar as well as geothermal (Ayompe et al, 2014). The main sources of commercial energy in Cameroon right now are hydropower, coal and petroleum, with 90 % of the population using biomass (wood) for cooking, heating and even lighting in remote areas (Muh et al, 2018). Access to electricity is estimated to be between 65 -88 % urban and around 14 % for rural populations. Cameroon is a net exporter of energy, due to its oil reserves, with an estimate of about 200 million barrels (as of 2015) of oil reserves, with a production rate of 24.5 million barrels per year (Fulbright, 2015). Natural gas resources proven are estimated at 157 billion m^3 with a potential of over 550 billion m^3 (Fulbright, 2015). According to the International Energy Agency (IEA) 2014 energy balance of Cameroon, energy production was estimated at 9756 kilotons of which 50.2 % came from biofuels and waste and 39.7 % from oil (Figure 1.17 a). Energy consumption in 2014 was 6556kiloton with the residential sector on the lead with 68.7 %, followed by the transport sector with 16.4 % (Figure 1.17 b). With respect to sources of origin, 71.8 % of energy consumption in 2014 came from biomass (Figure 1.17 c), which dominates electricity generation in Cameroon by 69%, followed by self-production 22 %, with an installed capacity of 1558 MW in 2009. (I.E.A, 2014). In 2014, total electricity generation (IEA, 2014) was 6922 GWh (Figure 1.17 d), (73.2

% Hydro, 12.9% gas, 12.8 % oil and 1.0 % biofuels) and in sectorial consumption (total 5485 GWh), the industry is the highest electricity consumer with 54.9 % (Figure 1.17 e) apart from hydropower plants. The country's potential to produce electricity from biomass residues is estimated at 1072 GWh (I.E.A, 2014).

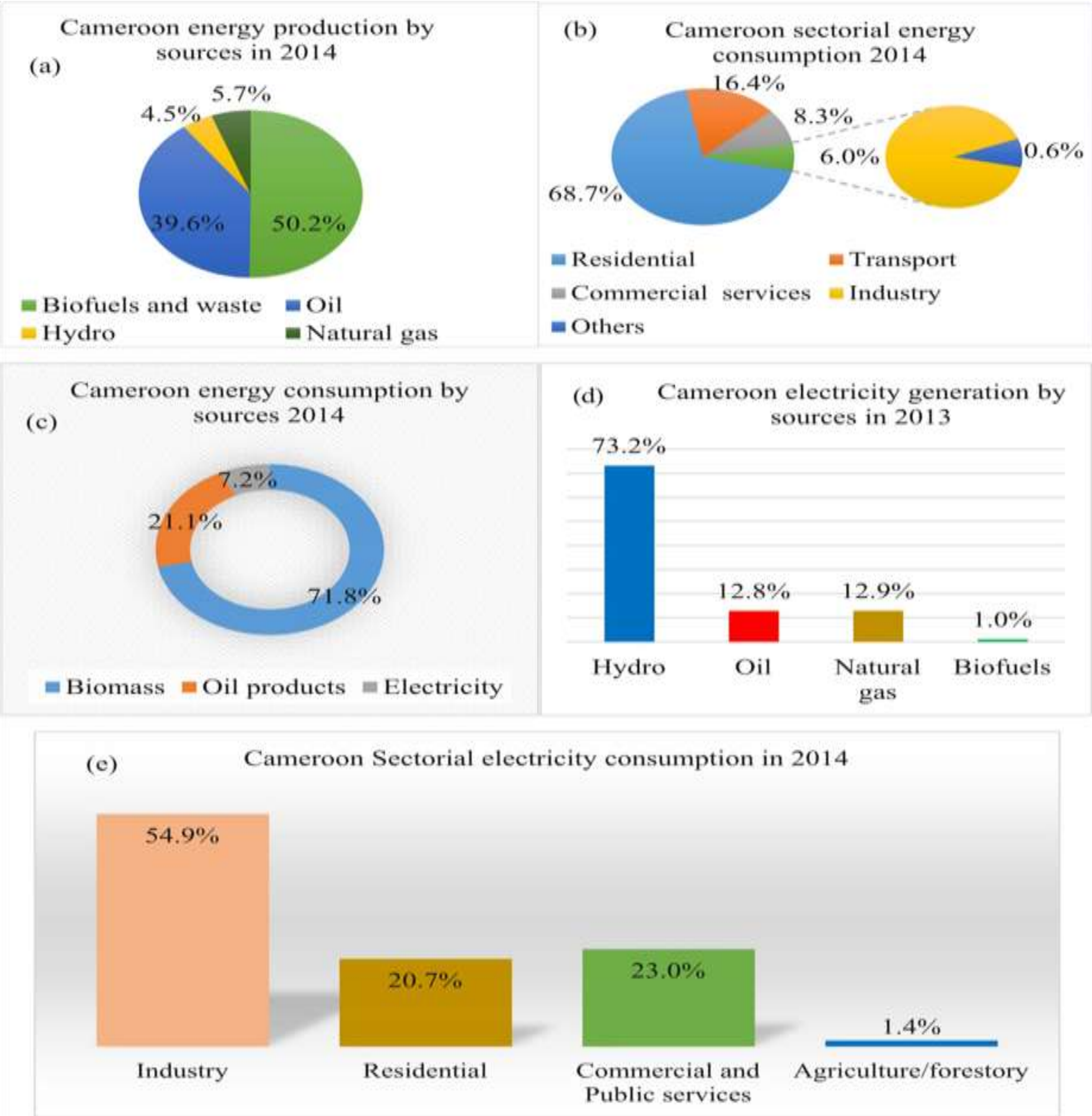

Figure 1.17. Energy sources in Cameroon

source: (Muh et al, 2018)

Amongst the oil products, kerosene is the most widely consumed due to low access of electricity mostly in the rural areas. It is estimated that two-thirds of the rural populations used kerosene for lighting, as well as ten per cent of urban dwellers (Mas'ud et al, 2015). For more than a decade now, Cameroon has experienced a strong economic growth (growth rate of 5.9 % in 2015, accompanied by a rapid increase in demand and consumption of electricity. This growth in demand for electricity is expected to continue rising over the next decade, as seen in the 2012-2025 demand forecast (Figure 17), using Business as usual scenario (BAU). The supplier of electricity (ENEO), responsible for the overall electricity system management (production, transmission and distribution), is actually struggling to meet the growing demand for power but is currently incapable of satisfying all needs, especially during peak periods. The state however is working on increasing generation capacity in the future. A number of energy infrastructural projects (hydropower, thermal and renewables) have been planned for development, some currently under construction and others getting completed. Projects such as the Kribi thermal gas plant (150 MW), Nachtigal hydropower plant (280 MW), Lom Pangar dam (170 MW), the Menve'ele dam (200 MW) dam, as well as the rehabilitation of the Song-Loulou and Edea Power plants to increase their generation capacity by 30 MW (Tatietse et al, 2010). However lengthy delays in these projects will certainly not provide rapid and lasting solutions to the current imbalance in electricity demand and supply. Thus, there is a high need to explore alternative means of power generation, especially the renewable sources.

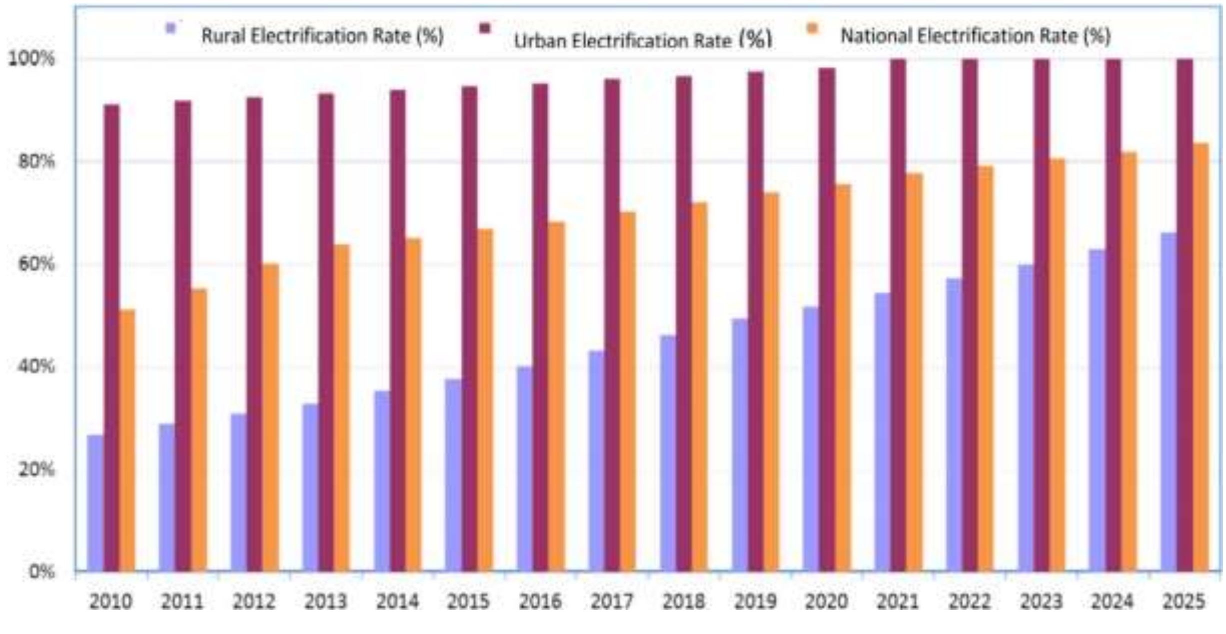

Figure 1.18. Estimated increase in energy demand over the years

Source: Lighting Africa Report, 2012

1.6.1. RENEWABLE ENERGY POTENTIAL

Economic growth depends on the availability of reliable, consistent, secure energy supply and resources. The lack of a reliable and consistent power supply in Cameroon is among the major hindrances for investors and this has caused the country close to a 2 % annual loss in GDP (Wirba et al., 2015). According to Lighting Africa Policy Report 2012 (L.A.P.R, 2012), the introduction and proper implementation of off-grid, low-cost, reliable and durable lighting options (including renewables) in Cameroon will result in rapid growth in electrification rates and energy access in the rural and urban areas between 2010 and 2035. (Kenfack et al., 2021) had earlier shown that, Cameroon has a great potential for renewable energy in solar, wind, biomass, geothermal and hydropower. However, only Hydropower plays a major role in Cameroon's energy sector with 75 % of electricity generation. The status of solar energy is exploited with the to demonstrated its importance in rural areas especially for the Northern part of the country.

1.6.1.1. Solar energy

Due to its geographic location, Cameroon has moderate to high levels of Global Horizontal Irradiation. Figure 2.13. maps the photovoltaic power potential in the country. Literature in solar energy studies provides limited information. assessed the solar energy readiness in Cameroon by highlighting the irradiation pattern across the country underscored that the mean solar irradiance is roughly 5.8 kWh/m^2/day in the Northern regions, while it's in the range of 4.0–4.9 kWh/m^2/day in the Southern regions of the Country. The lack of reliable network of surface observation stations for collecting weather data according to (Ayompe et al., 2013) has led to assess the energy output, capacity factor and performance ratio of PV systems using site-specific solar irradiation from long-term satellite-derived datasets accessible in Solar GIS software.

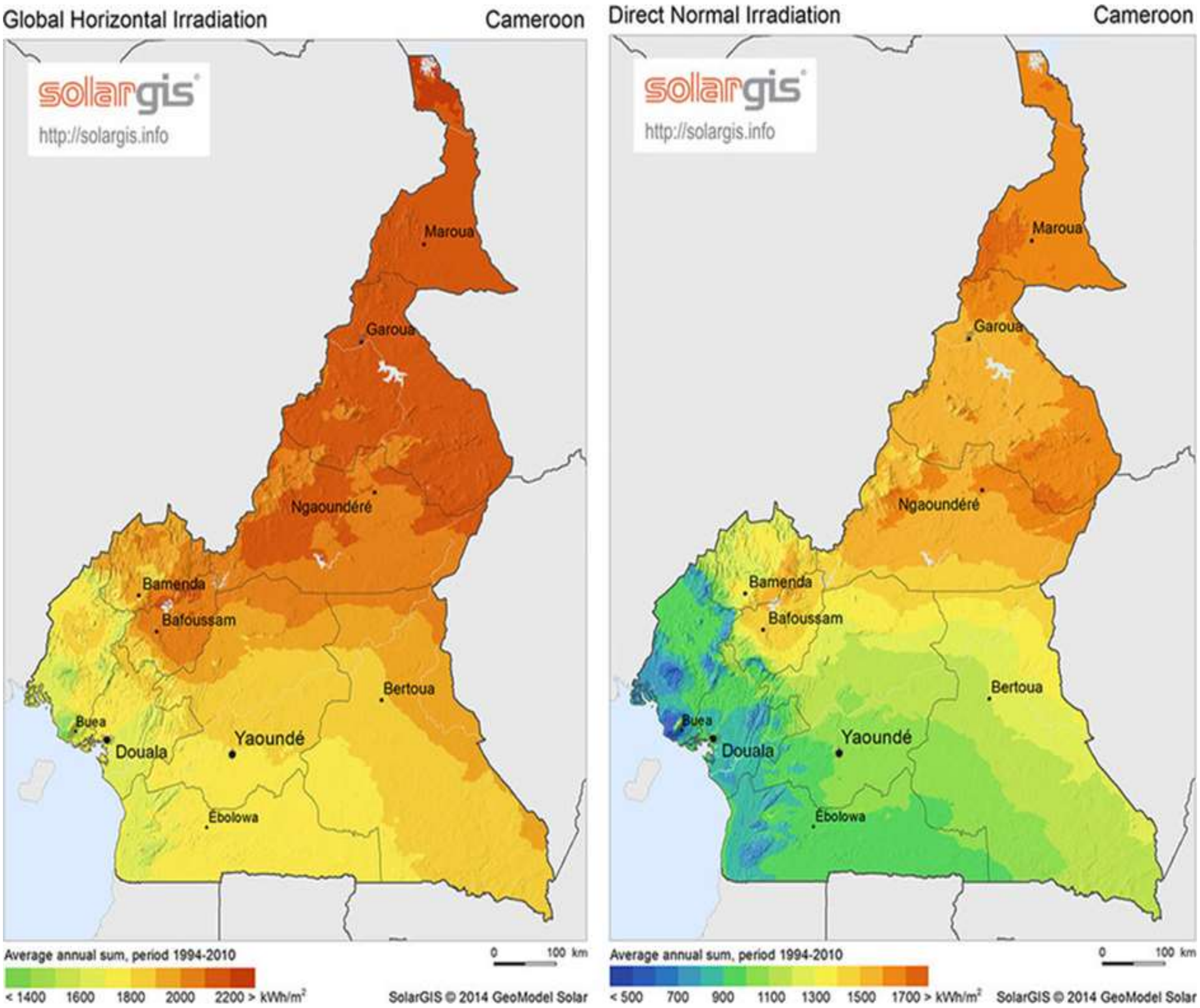

Figure 1.19. Cameroon Solar potential map

(Source: www.solargis.info)

Solar energy potential available in the country is massive, despite a poor commitment of the Government of Cameroon (GoC) to boost the solar energy sector. At the moment, solar power is applied in distributed generation systems in Cameroon, particularly to power cellular telecommunications networks. Solar thermal energy is used traditionally to dry agricultural products, fish, fuel, wood and clothes About 50 PV installations currently exist in Cameroon. The country has installed energy –keep it simple and safe (e-kiss) PV mobile off-grid systems from Antares (Muh et al., 2017) which generate electricity on a standalone basis. This technology can supply energy up to 2 KW, enough to power rural areas without access. Equally, there is the use of solar energy for street lighting in most towns in Cameroon with already installed PV lighting systems on major streets and public sites.

1.6.2. CAMEROON'S POLICY ON RENEWABLE ENERGY

Despite the well-established power sector framework, there is still a lack of adequate regulation and institutional setting for the off-grid, renewable energy and energy efficiency sectors (Africa-EU, 2012). The government is still working on a specifically dedicated text for renewable energies and another on energy efficiency. Nevertheless, the specific legislation relevant to promoting renewable energy or specific clean technologies is found in the general legislation concerning the electricity sector i.e., in the law No. 98/022 of December 24, 1998 focused on hydroelectricity only (Ackom et al.,2013). Afterwards, the electricity Law 2011/022, governing the electricity sector and promulgated on December 14, 2011, clearly defined RE sources. Key changes under this new legislation included the role of the state in:

- ensuring the promotion and development of RE;
- establishing the opportunity for the transmission system operator or any local distributor to purchase the surplus of electricity generated from RE sources;
- fixing tax benefits for products, goods and services intended for RE exploitation;
- Creating an agency responsible for the promotion and development of RE.

Overall, the country's energy policy takes into consideration the use of solar energy and other renewable energies (OECD/IEA, 2010) for solar energy production, but a renewable energy policy is being prepared to increase the share of renewables in power and heat generation and to involve private sector capital in the delivery of energy (Ackom et al., 2013). In Cameroon, the existing institutions responsible for RE production:

- The Ministry of Energy and Water Resources (MINEE), in charge of implementing government action in the RE sector, overseeing energy sector activities, formulating policy, laws, and directives for the promotion of RE;
- The Ministry of Economy, Planning, and Regional Development works with MINEE to promote investments in the electricity sector;
- The Ministry of Finance provides financial support and different incentives, such as Value Added Tax (VAT) exemptions, to boost the renewable energy sector;
- The Ministry of Scientific Research and Innovation is responsible for conducting research in the energy and hydrological fields and, in conjunction with MINEE, is responsible for promoting new energy;

- The Ministry of Environment, Protection of Nature and Sustainable Development is in charge of the promotion of sustainable development in the renewable energy sector;
- The Rural Electrification Agency is a legal public entity with financial autonomy, focused on promoting and implementing rural electrification in Cameroon and managing the Rural Energy Fund;
- The Electricity Sector Regulatory Agency is responsible for policy and regulatory framework and possible funding, regulating the electricity sector, setting electricity rates, and determining electrical standards. The agency is also in charge of the promotion and the follow-up of the use of the primary sources of energy, in particular renewable;
- Electricity Development Corporation (EDC) is a state-owned company that develops the electricity sector, including all hydroelectric projects in the country;
- ENEO Cameroun is the main utility company responsible for the distribution of electricity;
- SONATREL is the national power transmission utility company, a public administrator and operator of Cameroon's transmission network, a state-owned agency, with Cameroon government as the sole shareholder.
- Independent power producers (IPPs) are private distribution companies.

CHAPTER 2. MATERIAL AND METHODS

This chapter describes the study area, the material used, and the steps, taken to achieve the objectives set in the introduction of this thesis.

Materials consist of the tools (equipment) that have been used to collect data, design, and represent the technique used to generate electricity for the Garoua city council. The principal instruments used here were questionnaires, phone camera and GPS, and information and technology tools.

The research methodology employed in this work follows both a quantitative and qualitative approach. The quantitative approach was employed to collect statistical data whereas the qualitative was used to obtain information about the current energy situation of Garoua. This area was chosen because of the unavailability of sufficient energy to meet the population's daily needs despite their potential in solar radiation which could be converted to electricity to meet the population's energy. Electricity in this part of the country is being rationed presently in the main city and rural areas completely lack access to electric energy.

2.1. PRESENTATION OF THE STUDY AREA

2.1.1. GEOGRAPHICAL LOCATION

Garoua is a port town and the capital city of the North region, located in north-eastern Cameroon. It is situated in the Beneou division between latitude 9.3 ^{o} North and longitude 13.4 ^{o} East at an elevation of 249 m above sea level. It lies along the right bank of the Benue River, northeast of Yaoundé. Garoua is the chief commercial center of the North region and is situated at the junction of the Maroua-Ngouandere road (Britannica, 2009). This is illustrated in **Figure 2.1.**

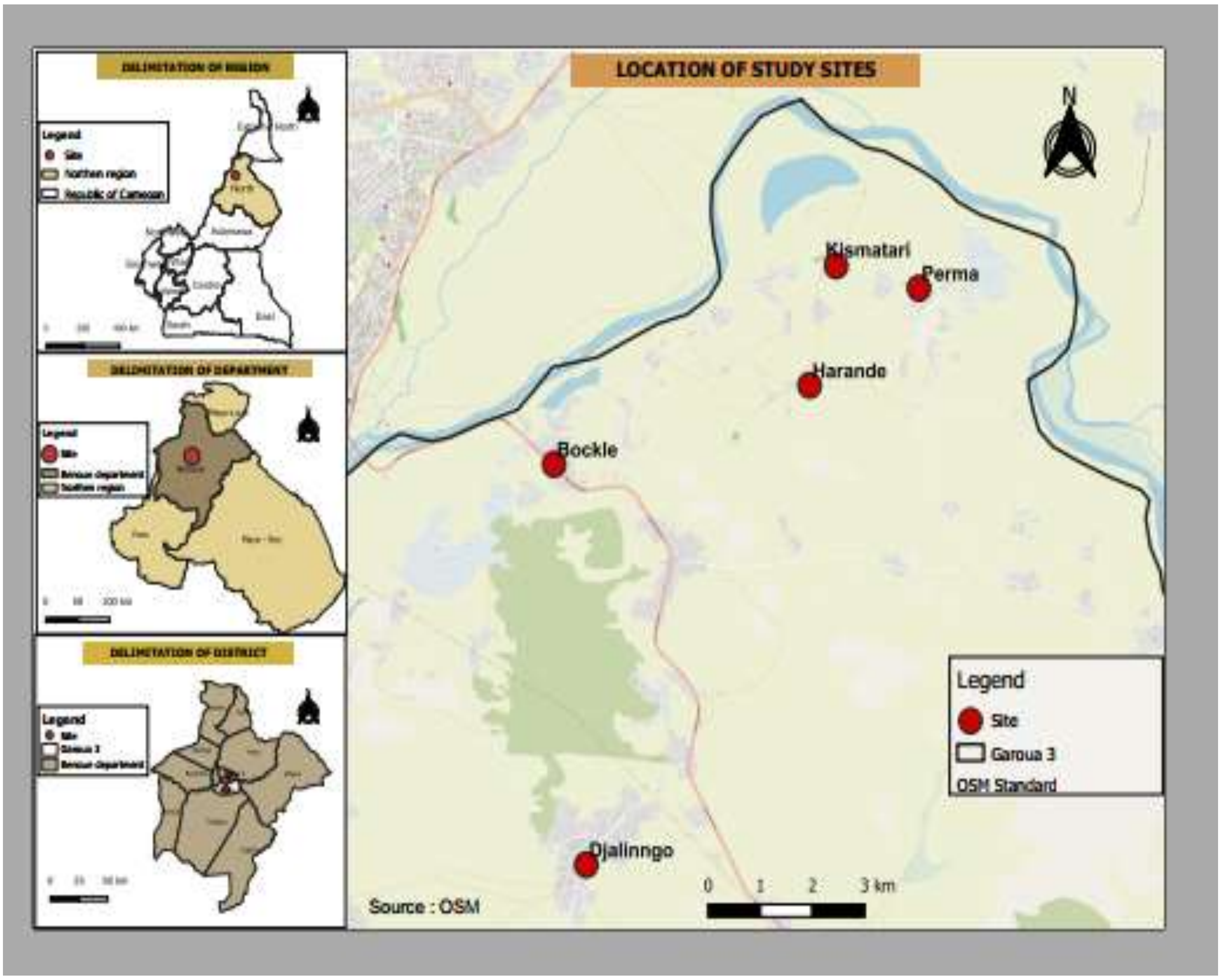

Figure 2.1. Geographical location of study area.

2.1.2. DESCRIPTION OF BIOPHYSICAL ENVIRONMENT

2.1.2.1. Climate

Garoua experiences a tropical Sudano-Sahelian climate type characterized by two main seasons; a long dry season from October to April, and a short rainy season from May to September. The annual rainfall reaches 1000 mm and this poor spatiotemporal distribution of rainfall remains the main climate hazard. It is manifested by the late or early arrival of the rain, the early cessation of rain coupled with long-term droughts. Garoua records high temperatures of 40 °C to 45 °C in April, with an average of 24 °C. However, irregularities can be observed from year to year or even from month to month as a result of changes in climatic conditions. Two types of wind blow in the locality mainly the monsoon and the harmattan. The monsoon is a humid wind that blows from south to north announcing the arrival of the rains while the harmattan is the dry wind blowing from the north to the south. These winds are often very violent destroying crops and houses. As for the relative humidity, it reaches 98 % in August and is around 15 % in February.

2.1.2.2. Relief

The relief is mostly made up of the Bénoué valley with an average altitude of 200 m and the rest is dominated by plains. These plains are interspersed with small mountain ranges forming inselbergs, especially in the Bocklé neighborhood and visibly constituting the great. Tinguelin Mountains of Pitoa. The plains are also floodable most of the time

2.1.2.3. Vegetation

The vegetation includes several types of Sudanian woodland (from tall Isoberlinia-dominated and other woodlands in the south-centre, to shorter, more open, mixed wooded grassland in the north), dry Anogeissus forest, semi-evergreen riparian forest and thickets along the Bénoué and its major affluents. The level of the sandy Bénoué river fluctuates much seasonally and exposed sandbars provide habitat for plovers and other waterbirds in the dry season.

2.1.3. SOCIAL AND ECONOMIC ENVIRONMENT

2.1.3.1. Demography

Garoua covers a total surface area of 644.72 km^2 and a population of 361000 inhabitants in 2020, this gives a population density of 560 inh/km^2. The city had a population of 32000 inh in 1950 and has grown by an annual growth rate of 5.7 % since 2015. Garoua is composed of 3 municipal councils ruled by mayors elected by the population. The city mayor governs the municipal councils and aims to attain the town's economic, social, environmental and cultural development. The figure below illustrates population growth in Garoua over the years and the respective annual changes. The graph also shows population projection for the next 15 years.

The main ethnic groups found in Garoua are the Haoussa, Toupouri, and Fali and dwellers from neighboring countries such as Nigeria, Tchad, Mali, and Senegal. The principal language spoken in this town is the Fulfulde and l’Haoussa. The presence of other natives in this locality is synonymous with peace and stability which is experienced by the local populations who are recognized for their hospitality. Garoua has an outstanding number of primary and secondary schools.

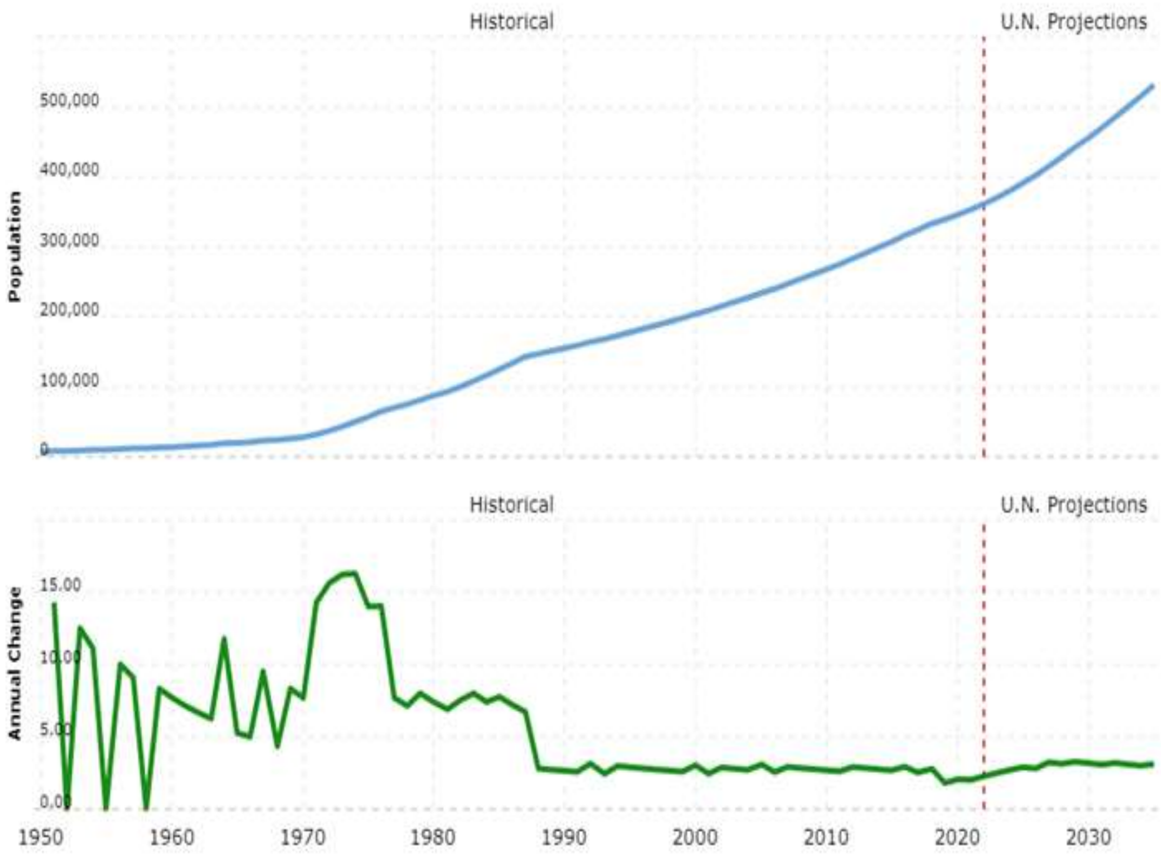

Figure 2.2. Garoua population graph

(Source: World bank, 2019)

2.1.3.2. Economy

As the fourth-largest port in Cameroon, Garoua is a major Centre of trade in the country. Most of the activities are those that generate jobs and income. These activities are mainly agriculture, livestock, fishing, cotton, trade, craft processing, and natural resources with the principal activity being agricultural production. It has long been a thriving center of the cotton industry and houses several textile processing facilities and factories. The cotton company Sodecotton has one of its major centers in the city. Economic life is driven by two large weekly markets of great importance.

2.2. MATERIAL

The following materials and tools were of great assistance for the realization of this study:

- ❖ A phone camera to take pictures;
- ❖ A questionnaire for data collection;

- A laptop computer for registering the work;
- A software ‘PVsyst ‘was used for simulation;

The attestation of research gotten from school and signed by the head of the department for Environmental Engineering served as a major pass, a visa to easily gather information and access documents from the authorities. It defined with precision the purpose of the research.

2.3. METHODS

To attain the objective of this work, both quantitative and qualitative research methods were used

2.3.1. COLLECTION OF SECONDARY DATA

This stage involved the consultation of documents such as thesis and dissertations, journals, articles, webpages on and about the subject matter to ensure that the objectives set were issues that needed to be addressed in the study area and has significance for society and the environment. It also involved the establishment of a:

- A plan to carry out fieldwork;
- A design of solar farm;
- A study of how to use the PVsyst software so as to portray the results.

2.3.2. COLLECTED OF PRIMARY DATA

To meet the objectives of this work, fieldwork was carried out through the use of questionnaires and group discussions with the village dwellers. The objective was to gather first-hand data concerning the town's energy demand and electrical situation and to understand their needs as far as electricity is concerned.

2.3.2.1. Fieldwork

Fieldwork was carried out to collect primary data using the following steps:

- Identification of the different councils and their needs for electrification;
- A survey to determine the energy demand of the population;
- Group discussion with the dwellers of the selected villages.

This permitted us to be able to get firsthand information, describe the geographical environment as well as the socio-economic situation of our zone of study. This critical information could not have been gotten otherwise without the field.

2.3.2.2. Questionnaire

In the course of this work, a participative approach was employed for data collection through the use of questionnaires. The objective of the questionnaire was to obtained first-hand information about the energy situation and their daily activities. The survey procedure employed here was both a qualitative one with a semi-structured interview and quantitative approaches which had as objective to evaluate the energy needs and demand of the chosen population. This questionnaire was administered through group discussions and face-to-face interviews.

The number of participants was achieved by aiming for as many respondents as possible while taking into account the proportion of the village's population. Group discussion was carried out in the locality of Harande meanwhile home visit was conducted with 50 and 30 questionnaires in Perma and Djalingo Tchoumpa villages respectively. The questions were written in English and French and translated to the native language in some cases for easy understanding. These questions were read out loud to the respondents to help those with limited literacy levels. An explanation was also given when they were unsure about their understanding of the questions. **Table 2.1** shows the participant's attributes and sample size.

Table 2.1. Participants' attributes and sample size

	Perma	**Djalingo**	**Harande**
Number of respondents	50	30	80
Total population of the village	1469[1]	702	319
Average age	40	45	40
The percentage went to school	50	30	25
Location of survey	Home visits	Home visits	Focus discussion
Percentage of male participants	60	80	100
Percentage of female participants	40	20	0

[1] Répertoire actualisé des villages du Cameroun

A total of 160 individuals residing in the study areas responded to the survey. This phase of the work ran for two weeks, the questions were both in English and French and each questionnaire was divided into four parts as follows:

- The respondent's necessary demographic information such as age and level of education.
- Energy use for basic needs-related information such as lighting, refrigeration and
- Household income.
- Time- use questionnaires which interrogated their activities throughout the day, duration, and time in the day.

2.3.3. CASE STUDY

The option of a case study was solicited to better and easily attain the above set objectives. The main criterion that guided the choice of selection was the complete lack of electricity in most parts of the cities due to no national grid extension. For this reason, three villagers namely Harande, Perma and Djalingo in Garoua III city council were selected. These villages are all located around the same neighborhood and face practically same electricity difficulties. The villagers need to move great distances from the villages to town just to get their phones charged and rely mostly on biomass and battery torches for home lightening at night. Additionally, the level of insecurity is relatively high at nights and students are unable to effectively study at night. Of the five villages visited, 2 were partially electrified and 3 were completely non-electrified hence a standalone PV system was design and costed for these three villages with a present population of 2490 inhabitants. This model can be extended to the whole municipality

2.3.4. SIZING METHODOLOGY OF PV SYSTEM COMPONENTS

PV power plants use solar photovoltaic modules to produce electric power. They are made up of thousands of PV modules, used to produce electric power either for stand-alone systems or for grid integrations. These power plants produce electricity by converting solar energy directly into electricity through solar cells. The efficient performance of PV systems depends on several factors such as weather conditions (ambient and cell temperature) the type of PV modules and inverters, and the efficiency and standard test condition (STC) of PV modules. The STC is defined as being 1 kW/m^2 of full solar noon sunshine when the panels and cells are at standard ambient temperature of 25 ^{0}C with a sea level air mass (AM) of 1.5. It is therefore important to consider these factors when sizing a PV system.

Designing a perfect PV system for these villages involves sizing the main components of the system such as, solar array, charge controller, inverter and battery. In this section therefore, a brief description of designing these elements is detailly examined. This step is very important to the success of the project because of its significant impact on the project cost since under sizing the system will lead to dissatisfaction from the consumers while oversizing will lead to waste of resources and revenue. Furthermore, to determine the average yearly solar isolation for the location in which the system will be installed, it is necessary to determine the coordinates of the site, the energy demand of the population and get basic knowledge of the climatic conditions.

2.3.4.1. Design Load Estimation

Electric load consumption varies with time, consumer and location of the consumer. Thus, all electric power suppliers should factor in the variation of load during load estimation. In the course of this work, a survey was administered to three villages in the Garoua 3 municipality with a population of 2490 inhabitants to evaluate their energy demands for a period of 20 years which is assumed to the life span of solar panels.

To obtain the electricity demand for the three above mention villages, only the electric needs prioritized by the population were considered. These needs included appliances such as bulbs for lighting, television sets for entertainment, electric fans for cooling and telephones for communications. During the group talks and survey, the schedule of the population was used as a base to determine when the electrical equipment would be turned on or off. The detailed sizing methodology adopted for daily electrical load for a typical household is presented in table 2.2. It is worth noting that the total load estimation was calculated based on the following assumption:

- ❖ The villages' population use their appliance per schedules reported by them and will always turn off the electric equipment when not in use.
- ❖ A standard household is made up of four bedrooms, a kitchen, a living room, and a toilet, each using the type of bulbs indicated on the table 2.2.
- ❖ The equipment rated power remains the same in all three villages.
- ❖ The load profile was assumed to be the same throughout the year that is both in the rainy and dry seasons.

Table 2.2. Daily load consumption per household.

Appliances	Power (W)	Number in use	Total power (W)	Hrs/day	Wh/day
Bulbs in the living room	25	2	50	5	250
Bulbs in the room	10	4	40	6	240
Bulbs in toilet	10	1	10	3	30
The bulb in the kitchen	10	1	10	3	30
Phone charger	4	4	16	6	96
Electric fans	45	2	90	10	900
Tv set	120	1	120	12	1440
Total			**336**		**2986**

To obtained the daily load estimation of the villages in question, this total value was multiplied by the total number of household (415: assuming that each house is made up 6 individuals) in the villages and the design load was obtained using equation 2.1.

To appropriately determined the energy demand of the population while taken into account an increase in the load demand, a design load was calculated using equation (2-1).

$$E_d = 1.5 \times El \quad (2\text{-}1)$$

Where,

E_d is the design load.

El =daily load estimation and 1.5 is the Fudge factor accounting for efficiency losses, wiring and interconnection losses as well as the battery charging and discharging losses in the PV system.

2.3.4.2. Determination of solar insolation for the location.

Solar insolation refers to the total amount of solar radiation energy received on a given horizontal surface per unit time per unit area measured in (Wh/m^2). The amount of solar radiation a place receives is dependent on the time of the year and the latitude and longitude of the place. This data is important because all solar panels are rated assuming a solar irradiance of 1000 W/m^2 (standard test conditions STP). However, such radiation levels are seen only for a few hours around noon. Furthermore, our system has to be designed keeping in view the fact that it should work even during low light conditions in the rainy season. Monthly solar irradiance in (kWh/day m^2) data for a particular place is needed to provide a better estimate of average radiation wattage for the sunshine hours at that place. Irradiance data (both monthly and annual) was obtained from METEONORM in PVsyst. The horizontal global irradiation use in this work is 4.92 kWh/m^2/day representing the month with the lowest radiation in this location.

2.3.4.3. Sizing of the panel array

Different sizes of the PV modules will provide different amounts of power. To obtain the exact size of the PV modules needed, it is important to consider the system's nominal voltage against the nominal voltage of the panels. The panels can be connected in series/parallel to give the nominal system voltage. Any renewable energy source of electricity must be oversized to ensure that the battery can be recharged from a maximum depth of discharge in an acceptable period while still meeting the daily load requirements (Mbinkar et al., 2021).

- **Total Watt-peak rating needed for PV modules.**

The peak power (Ppeak) of the photovoltaic installation is a function of the watt-peak rating and defined as the expected daily energy consumption divided between the peak solar hours and the expected performance of the PV array (ηpv) and given by equation (2-2).

$$\boldsymbol{P_{PVpeak} = \frac{Ed}{Hp}} \qquad (2\text{-}2)$$

Where:

P_{PVpeak} correspond to the peak power required from the solar panel (kWp)

Hp represent the average daily solar irradiation (hrs)

Ed corresponds to the total daily energy consumption (kWh/day)

In the present study for designing of PV system, PV module of 350Wp, 28 V rating is considered due its high efficiency and availability in the market.

Calculation of number of PV panels needed for the system.

The number of modules needed for the system to function is obtained by dividing the peak power by the rated output Watt-peak of the PV module available. Any fractional value obtained is rounded to the nearest whole number with the least sunny month considered in the calculations. This is given by equation (2-3).

$$N=\frac{Ppvpeak}{Pm} \quad (2\text{-}3)$$

Where;

P_{pvpeak} is the peak power required by the PV array in (Wp) and

Pm is the peak power of a single module in (W).

To get the voltage to be use for the PV system, a few details are taken into account, such as

- The power rating of the PV modules.
- The geographical extension through which the installation is going to be made.

For a particular power rating, in case a weaker voltage is chosen, it will result in high current generation, which may result in losses at the level of the conductor. To have the best performance, which will also be economically beneficial, the voltage is chosen as follows;

Table 2.3. Recommended voltage for power rating

Power of the PV array (W)	0-500	500-2000	>2000
Recommended voltage (V)	12	24	48

Source: Njonkep, 2016

2.3.4.4. Sizing of the Battery

The capacity of the storage batteries needed depends on the requirements for the system to deliver uninterrupted supply, and the amount of money available to provide for this privilege. In most cases, it makes sense to provide sufficient storage capacity to ensure that electricity should be available for three to five consecutive days without sunlight. For improving the life of a battery and consecutive non sunny days, the number of autonomy days in this work is considered to be 1 day. However, batteries should not be completely discharged, as this reduces their useful life (Mbinkar et al., 2021). The battery bank size in ampere is given by the following equation (2.4) and the total number of batteries needed by equation (2-7).

$$\text{Battery bank size (Ah)} = Autonomy\ days \times \frac{Ed(\frac{Wh}{day})}{operational\ voltage(V)} \qquad (2\text{-}4)$$

Number of batteries

$$\text{Number of batteries connected in parallels} = \frac{Battery\ bank\ size\ (Ah)}{Ampere\ hour\ of\ each\ capacity\ (Ah)} \qquad (2\text{-}5)$$

$$\text{Number of batteries connected in series} = \frac{sytem\ voltage}{voltage\ of\ battery} \qquad (2\text{-}6)$$

$$\text{Total number of batteries} = \text{series connection} \times \text{parallel connection} \qquad (2\text{-}7)$$

2.3.4.5. Sizing of inverter

They are responsible for converting direct current to alternating current and should never be equal or lower than the PV array size. The maximum continuous input rating of the inverter is about 10% higher than the PV array size. It accounts for allowing the safe and efficient operation of PV power system. To size the inverter, the possibility that all the load may be turned on at the same time and run continuously is considered. This, however, means that most of the time that the inverter is running, it is operating at a smaller load than its rated load. Running the system at a lower load reduces efficiency and consequently wastes some energy. The inverter capacity can be calculated by equation (2-8).

$$\text{Inverter size} = P_{PVpeak} \times \text{oversize factor} \qquad (2\text{-}8)$$

Where the oversize factor is given as 1.25 according to the National Electric Code and P_{PVpeak} is the PV array size (Wp).

2.3.4.6. Sizing of charger controller

The charge controller capacity can be determined based on the PV array size and battery banked designed operating voltage such as 48V. In selecting the controller, the output voltage rating should be equal to the nominal battery voltage. Also, the maximum PV voltage should be less than the maximum controller voltage rating. The charge controller capacity is calculated using equation (2-9).

$$\text{Charge controller capacity} = \frac{PV\ array(Wp)}{battery\ bank\ design\ voltage(V)} \qquad (2\text{-}9)$$

2.3.5. MODELLING AND SIMULATION

To test the hypothesis of solar PV systems to generate sufficient energy for the villages in the Garoua III council, we empirically design and simulate a solar PV system plant for the three above mention villages as a test sample where solar energy abounds. The methodology followed in this work started by generating the meteorological data of the chosen villages using METEONORM. METEONORM software is a complete weather database largely used in modelling various energy systems and processes. It also contains algorithm to calibrate the weather data around the world, with the possibility of adjusting many meteorological parameters. The data related to energy used were collected for a typical household and multiplied by the total number of households in the villages located in the same rural region. Based on the above sizing formulas, a preliminary design was done to identify the appropriate characteristics of the main standalone PV system (SAPV). With the input data obtained, the simulation of the overall SAPV system was performed using the PVsyst software version 7.2. This software is popularly used for solar PV panel sizing, provides various information such as solar irradiation potential estimation, energy production and installation costs. The main factors considered in this design include the solar resources that indicate the average daily radiation for each month based on the longitude and latitude, the PV panel, the primary load, the battery type, the convertor type and the battery charge controller type.

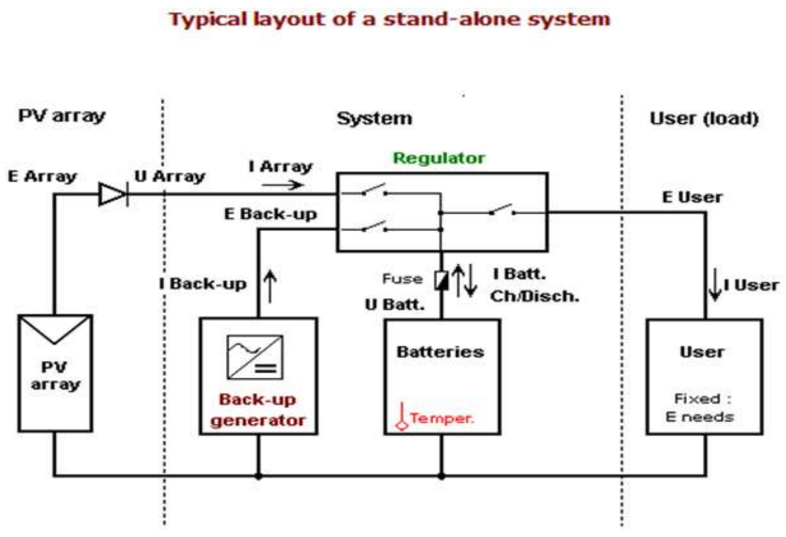

Figure 2.3. Typical layout of the PV system

2.3.6. ECONOMIC ANALYSIS

PV systems are often considered as a clean energy solution which is friendly to environment, however, on the other hand, PV systems are also valuable in financial issues. With effective design and operation, PV system may pay back its investment and have further profit. Some PV systems have lower cost than other type of generations. To decide the cost and value of a PV system, an economic analysis is conducted in this study. To analyze the economy feasibility of this work, the capital cost of the PV system is calculated alongside with the capital investment costs and the maintenance and operational costs. The life cycle cost (LCC) method was use in these studies to determine the estimated cost of the propose stand-alone PV system. This method covers all the total cost of owning and operating an item over its lifetime, expressed in today's money. Furthermore, the life cycle cost estimation is evaluated. This work adopts the mathematical values presented in evaluating the PV array cost, the initial cost of batteries, the inverter cost, the charge controller cost and the installation cost (Akinsipe et al., 2020).

It is worth noting that, the life cycle of the PV system is considered to be 20 years while other components of the system such as the storage system are subjected to periodical maintenance between 5-10 years. Thus, evaluating the life cycle analysis is performed based on the PV system life span of 20 years.

2.3.6.1. Cost estimation of standalone PV system components

- **The cost of a PV array**

In the present study, monocrystalline type PV modules are used and as reported by (Akinsipe et al., 2020) the unit cost per peak what is taken to be USD 1.94/Wp, and it is mathematically calculated using equation (2-10).

$$\text{Total cost of PV array} = \text{peak power} \times Cost/Wp \qquad (2\text{-}10)$$

- **The initial cost of batteries**

The cost of the battery is calculated based on actual size of the battery bank. Equation (2-11) is used to calculate the battery back cost. The initial cost of the battery is evaluated using the equation below while taken considering the unit price of the battery to be $ 2.2/Ah.

$$\text{Cost of battery bank} = \text{capacity of battery} \times \text{cost/Ah} \qquad (2\text{-}11)$$

The cost of an inverter system

According to (Akinsipe et al., 2020), the unit price is taken to be $ 0.31/W and this is calculated following equation (2-12).

$$cost\ of\ inverter = inverter\ capacity \times cost/W \qquad (2\text{-}12)$$

The cost of the charge controller

The cost of the charge controller is determined by multiplying the capacity of the charge controller by the unit cost following equation (2-13). The cost of charge controller is $3.5/A as reported by (Akinsipe et al., 2020).

$$cost\ of\ charge\ controller = charge\ controller\ capacity \times cost/A \qquad (2\text{-}13)$$

2.3.6.2. Capital cost of standalone PV system

The capital cost of PV system includes the structure cost and cost of land of the PV system. In this project the land required for the available projects is assumed to be available therefore no cost will be enquired for land purchase. The structure cost is 20 % of the total PV system components cost and is widely assumed all over the world as reported by SECO. Based on these assumptions, the capital cost (Ci) for the SAPV system is determine following equation (2-14).

$$Ci = cost\ of\ (PV\ array + Battery\ bank + charge\ controller + inverter + structure\ cost + installation\ cost) \qquad (2\text{-}14)$$

It is worth noting that the installation cost makes up 10 % of total PV system and further includes transportation cost.

2.3.6.3. Operation and maintenance cost of the SAPV system

The operating and maintenance cost for the proposed PV system is 2 % of the capital cost of the system. The calculation of the operating and maintenance cost of the system is as given by Equation (2-15).

$$Co\&M = 2\%\ of\ Ci \qquad (2\text{-}15)$$

2.3.6.4. Replacement of battery bank system

The life of the PV module and battery consider in this work is considered to be 20 years and 5 years respectively and the life cycle cost analysis is based on the life time of both the PV and the battery. The inflation rate and discount rate are the essential aspects for determining the life cycle costs of the PV system (Corporation & Salehin, 2016). This paper assumes the inflation rate and discount rate of 4.6 % and 4 % respectively according to Cameroon National Institute of Statistic 2021. The replacement battery cost is determine using equation (2-16).

$$C_{BR} = C_B \left[\left(\frac{1+i}{1+d}\right)^{N} + \left(\frac{1+i}{1+d}\right)^{2N} + \left(\frac{1+i}{1+d}\right)^{3N}\right] \qquad (2\text{-}16)$$

Where CB is the battery cost, i is the inflation rate, d is the discount rate and N the life span of the battery (taken to be 5, 10 and 15 years respectively).

2.3.6.5. life cycle costs of PV system

the life cycle cost (LCC) of the PV system includes the sum of all the presents worth (PW) of the total equipment costs (PV arrays, the inverter, batteries, charge controller), installation cost, structure cost and the operation and maintenance cost of the system. This is calculated using equation (2-18).

LCC= Total cost equipement cost +structure cost +installation cost + battery replacement cost + maintenance and operation cost *(2-17)*

2.3.6.6. Annualized lifecycle cost of PV system

It is the cost which will occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence. The annualized life cycle cost is calculated based on the parameters including the levelized cost, discount rate (d), inflation rate (i) and the lifespan of the project (N). The ALCC is best evaluated using Eq. (2-19) (Ghafoor et al., 2015).

$$ALCC = LCC\left(\frac{1-\frac{1+i}{1+d}}{1-\left(\frac{1+i}{1+d}\right)^{20}}\right) \qquad (2\text{-}18)$$

2.3.6.7. Unit electricity cost

The electrical energy unit cost (Uel) is the economic parameter that determines the validity of the PV system (Kaabeche et al., 2014). The cost of electrical energy is evaluated based on the ratio of the aggregate annualized cost of the system to the annual electrical energy generated (Sinha and Chandel, 2015), and it is calculated using Eq. (2-20) (El Shenawy et al., 2017).

$$U_{el} = \frac{ALCC}{Ec} \qquad (2\text{-}19)$$

Where E_C is the total annual electrical energy units consumed by the specified electrical load and is determined using equation (2-21) as follows:

$$E_C = \text{daily electrical load (kWh/day)} \times \text{Number of days/year} \qquad (2\text{-}20)$$

CHAPTER 3. REULTS AND DISCUSSION

This chapter presents the results of this work such as result gotten from the survey as well as the designing and costing of the solar plant system using both a predesign and PVsyst software. It is worth noting that all formula used in this chapter are same as stated in the methodology as well as the materials and method used in getting the results with an explanation as to why it has been used.

3.1. RESULT OF FIELD WORK

From the questionnaire, some general observations were made. The sample size used was made of a total of 160 individuals, a representative size of the three villages chosen.

DEMOGRAPHIC INFORMATION.

The aim here is to get an idea of the total number of people staying in a house, their level of education as well as their age group. The results obtained suggested that a typical household is made up of at least 6 individuals with most being in the youth group. The youth group here are aged between 5-17 years old making up 65 % of the village's population. Young adult group with age between 18- 30 years old make up 20 % of the village population meanwhile 15 % are above 40 years.

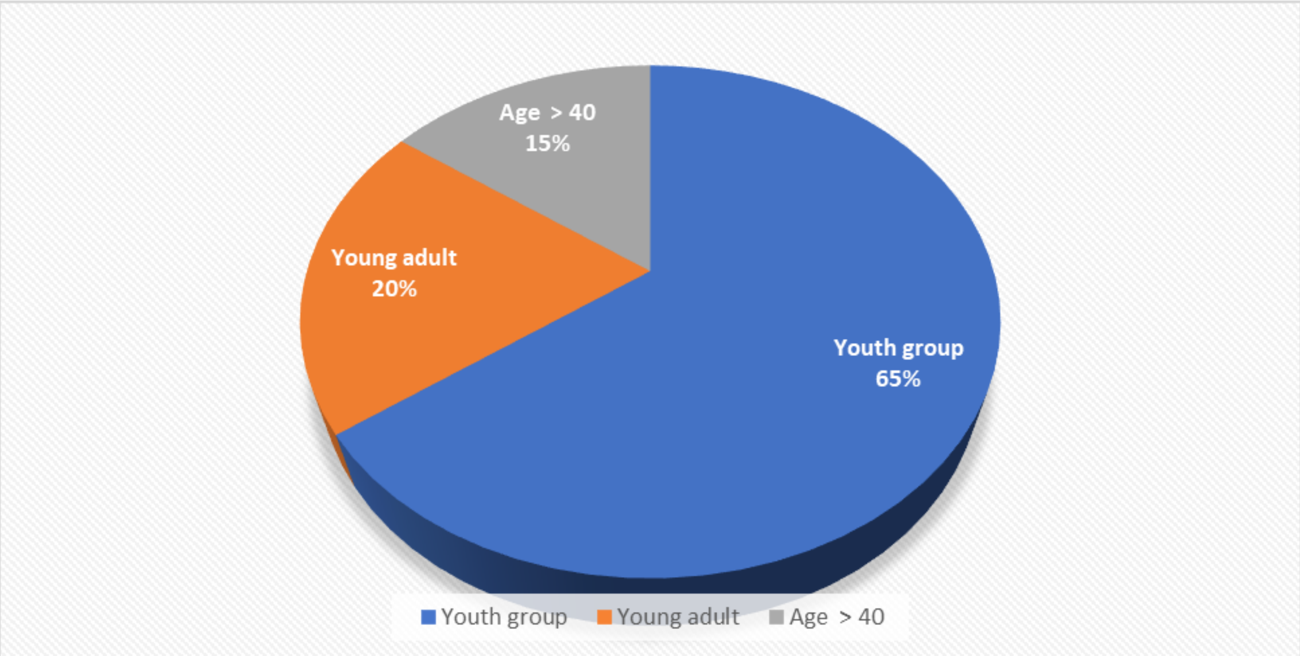

Figure 3.1. Demographic information of the population

HOUSEHOLD ENERGY SOURCES.

A first observation was aimed at identifying the different sources of energy used by the population for lighting. It was noticed that 15 % of the population use biomass (mostly firewood), 12.5 % depend on rechargeable and phone torches, 7 % use kerosene lamps for lighting at night while 65.5 % use all methods depending on the availability.

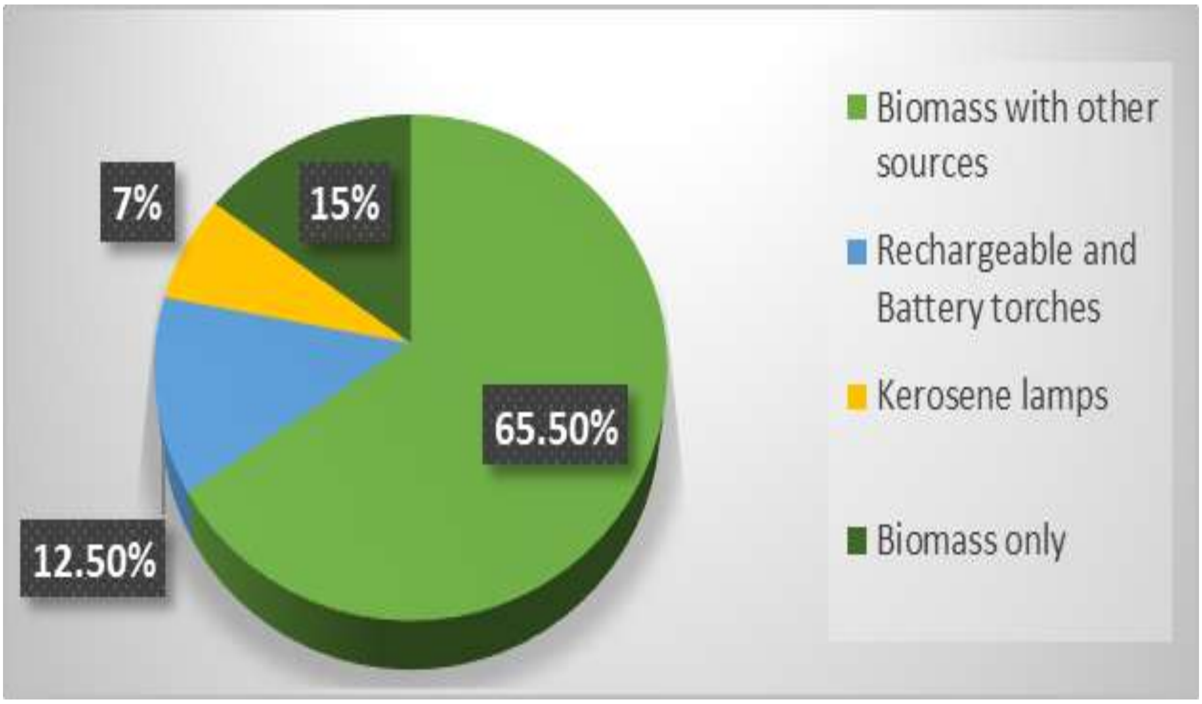

Figure 3.2. Sources of Biomass use by the villagers

DAILLY ACTIVITIES OF THE VILLAGERS.

This question aimed at understanding the different activities carried out during the day and night. This helped in determining the kind of appliances necessary for each household. It was notice that most of the 35 % population are primary and secondary students who spend most of their time in school during the day and will need energy only in the evenings and early mornings for studies while a 55.5 % of the population mostly are farmers and spend most of their day in the farm while others (mostly aged and infants) constated 9.5 % of the population and stay mostly at home during the day and will therefore mostly need energy in the evenings for entertainments.

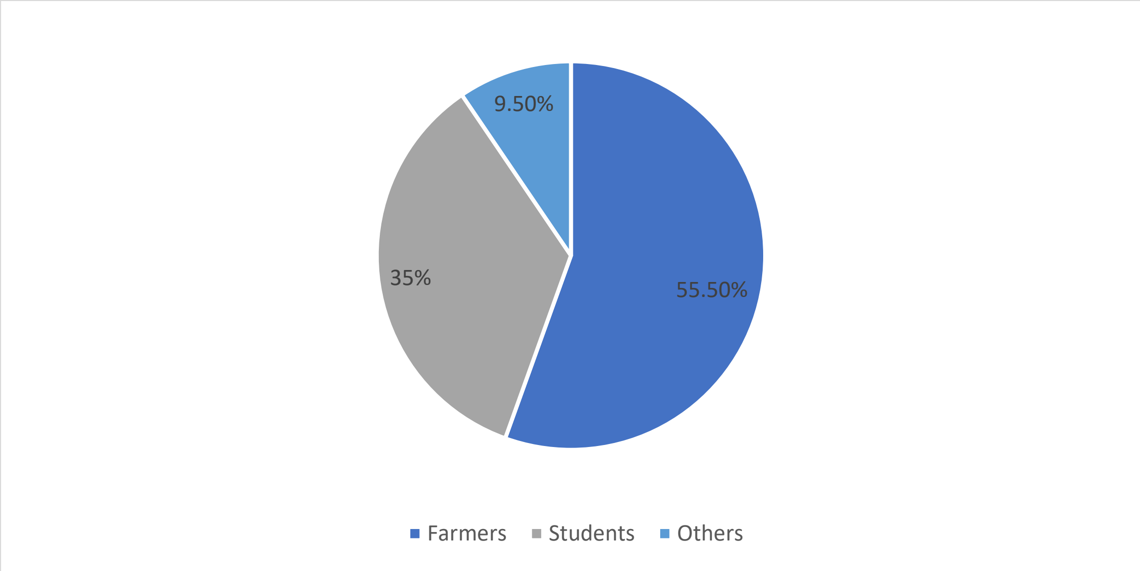

Figure 3.3. Daily activities of the population

WILLINGNESS TO SUPPORT ELECTRICITY GENERATION.

Before proceeding to investigations related to the willingness to have electricity, the need to evaluate the populations monthly income was deemed necessary. The objective here was to know if the population will be able to afford for their energy consumption. Of the 160 villagers who respondent to the questionnaire, 125 of them agreed that their monthly income could be partitioned and part used to pay for electric bill rather than spending 300 to 400 frs daily on conventional energy sources they are presently using.

Moreso, a few individuals were willing to support the installation of a solar plant for electricity generation both financially and manually. The result suggested that 80 % of the population are willing to move from traditional lighting source to modern (electricity) source meanwhile 12.5 % claimed to be satisfied with the present condition and 7.5 % did not give respond to their willingness to change or not.

3.2. DEMAND FOR ENERGY

The results of the electric load estimation for a typical household in the villages is 336 kW given a total daily energy consumption of 2.986 kWh/ d per household as shown in **Table 2.3.** To obtain the total daily load consumption for the three villages under study, the total daily load consumption per household was multiplied by the total number of households (415) to obtain 1239.2 kWh/d. These chosen villages will be electrified using photovoltaic power plant.

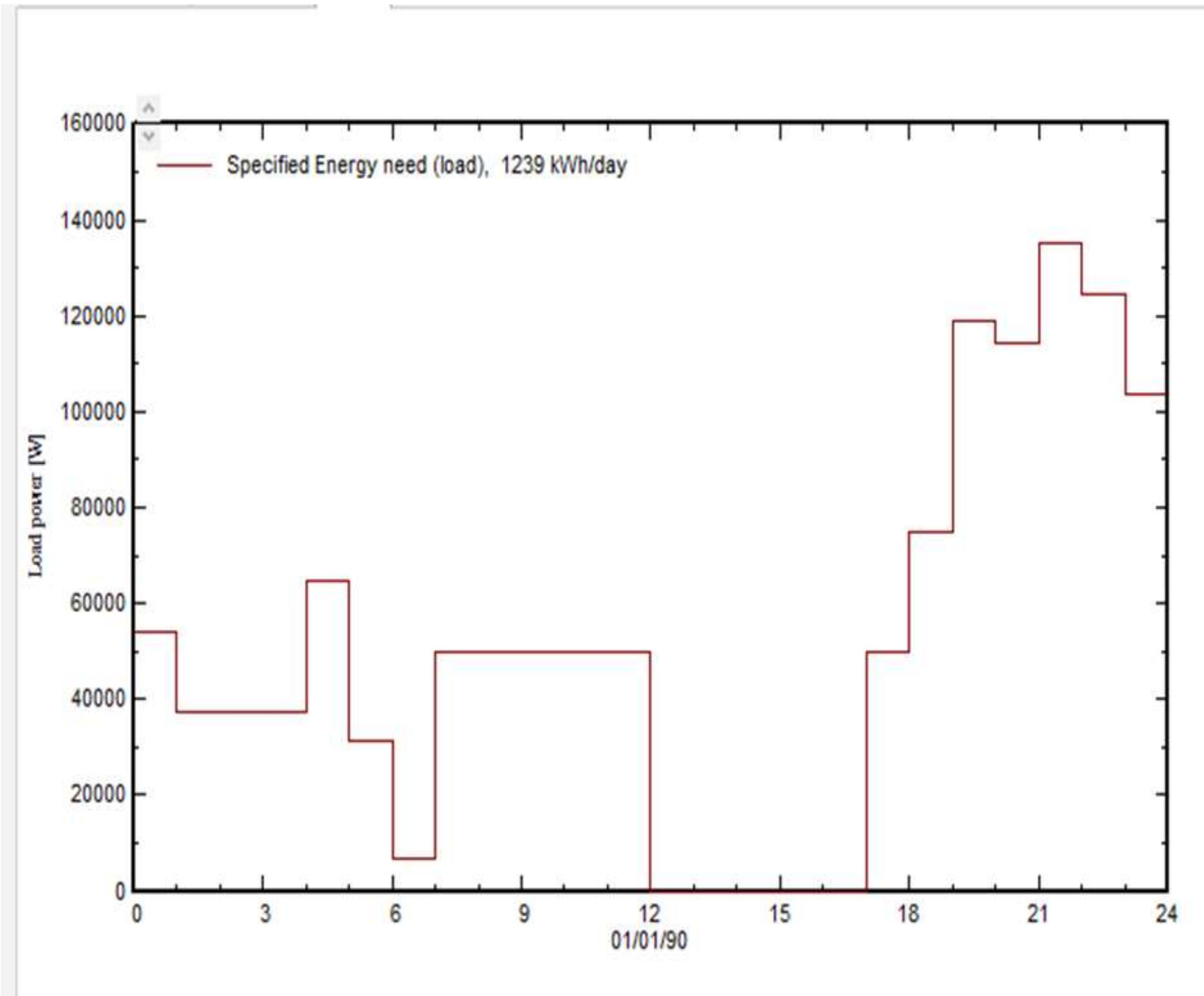

Figure 3.4. Daily energy load of the population

The maximum electricity load of the villages occurs mostly from 7pm to midnight as shown by **Figure 3.4.** As answered by the population in the questionnaire, this is the time when most of the families are at home enjoying television and students studying besides night light use. It is worth noting that the energy demand was necessary to be determined to avoid oversizing or under sizing the system.

METEOROLOGICAL DATA

To carry out the sizing of the PV system and the selection of the different components, it is necessary to determine the meteorological data of the selected area for which the system is to function. The weather data which includes temperature, solar irradiation, sunshine duration, wind velocity, humidity and radiation was taken from the software Meteonorn in PVsyst. Version 7.1 as presented in **Table 3.1.**

Table 3.1. Meteorological data of Garoua

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/day	kWh/m²/day	°C	m/s	[-]	%
January	5.90	1.92	26.1	2.60	6.848	27.4
February	6.13	3.19	29.5	3.00	7.000	22.7
March	5.86	3.06	32.3	3.00	7.000	24.6
April	5.94	3.15	33.0	3.10	7.000	38.2
May	5.78	2.83	32.1	3.09	6.880	49.0
June	5.47	2.79	28.8	2.89	5.852	66.5
July	5.25	2.80	27.7	2.60	4.836	74.7
August	4.92	2.77	26.4	2.21	4.480	82.0
September	5.23	2.50	26.8	2.09	4.886	80.5
October	5.66	2.53	28.4	2.10	5.347	64.4
November	6.36	1.46	27.8	2.31	4.879	43.6
December	5.87	1.60	26.3	2.40	5.428	33.3
Year	**5.69**	**2.55**	**28.8**	**2.6**	**5.870**	**50.6**
	Paste	Paste	Paste	Paste		

Global horizontal irradiation year-to-year variability 5.4%

Results of the monthly global and diffuse horizontal solar radiation, temperature, wind velocity and relative humidity are presented in **Table 3.1.** It can be noticed from the table that the Global horizontal radiation is highest in November suggesting a high energy generation and lowest in August indicating a lower energy generation. Furthermore, from the month of February till June, temperatures are high. This data indicates that the potentials of electricity generation from solar energy in the study area are high.

3.3. SYSTEM SIZING

For the design of the PV system, the appliances chosen were those necessary to provide the basic electricity needs of the population as shown in table 2.3. These main devices were those intended to be purchased by the population upon installation of electricity as mentioned by most during group discussion and door to door interviews. The power rating of the different appliances was then gotten from online sources (www.draftlogic.com). This was necessary to calculate the consumption rate of the villages and as earlier mentioned, all household in these villages uses same amount of electricity per day. The electricity generated is to feed a total population of 2490 inhabitants for a period of 20 years. The energy generated by this source can however meets the needs of a greater population in the nearest future since not all of it is immediately use upon production.

PREDESIGN OF SYSTEM

The predesign here constituted of manually sizing the different components based on the equations mentioned in chapter 2. Given that the principal objective was for lightening, the appliances were chosen with great care taking note of the power rating of each device so as to optimize the system and to make it more financial attractive. Additionally, the different components quality, market availability, cost price, efficiency and warranty over the development lifecycle was considered during selection.

Calculations.

The total daily power needed was calculated together with the daily energy needed and from there, the inverter size was calculated, the battery storage capacity calculated and the number of PV modules needed to supply the system was also equally calculated. From the power obtained, the right voltage to be used was determined together with some other design parameters.

- From equation (2-1) the design load of the system E_d,

  E_d= 1858.79 kWh/day

- From equation (2-2) the peak power was obtained,

  P=377.8 kWp

- Following equation (2-3) the number of solar panels needed was obtained,

  N=1079.43 thus 1080 solar panels.

With power rating of a single PV module at 350 W. This power was chosen due to its high efficiency and relative availability in the market. Following table 2.4, a voltage of 48 V was selected for our system since the rating power of our system was 377.8 kWc greater than 2000 W

Following equation (2-4), the battery capacity was evaluated to be,

C= 38724.69 Ah with an autonomy of 1 day.

In the present study, the stand-alone PV system has a battery bank which comprises of batteries each of 2 V and 3470 Ah capacity. This resulted in a total of 288 batteries with 12 batteries connected in series and 24 batteries connected in parallel. Furthermore, the voltage system was chosen due to the large size of the system and also to optimize the lifespan of the battery bank.

- The inverter and charge controller were equally size using equation (2-8) and equation (2-9) to obtained 472.25 kW and 7870.83 A respectively.

Figure 3.5 represent a scheme of the results obtained for a SAPV equipped with a battery bank, solar panels, charge controllers and inverter dimensioned to satisfy the average load with out the use of a grid system. The significance of opting for this source of electricity is as results of the fact that this part of the country in the last three years suffer from constant load shedding which led to electricity rationing. Despite the availability of a hydropower plants and a thermal power plant, seasonal factors such as no rainfall and high cost of petrol has led a low rate of electricity supply to this part of the country. To minimize cost of transportation, a stand alone system is more convenient for this remote areas which can equally be adopted for most part of the country which is yet to have electricity.

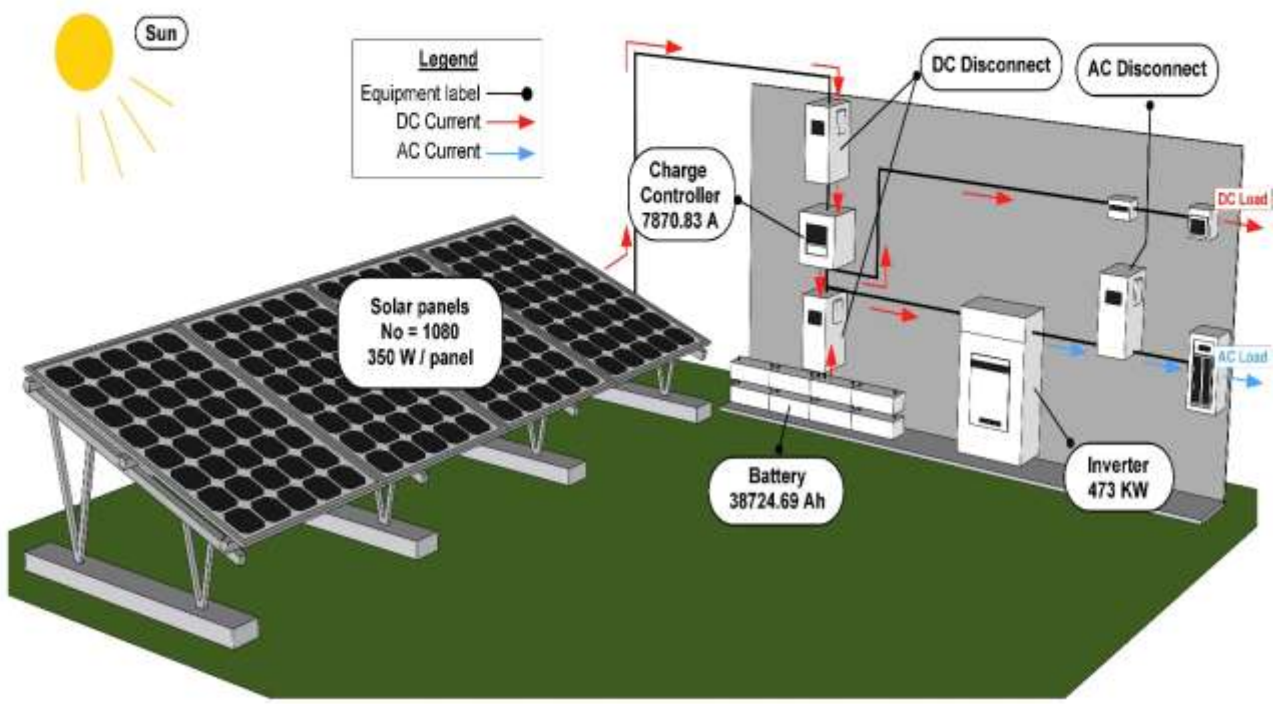

Figure 3.5. Schematic representation of SAPV

3.4. RESULTS OF SIMULATION

From the results of the simulation, three main parameters were assessed. The first parameter is the total energy produced from the PV system on annual basis which is referred to as available solar energy (E_ Avail) is 645.718 MWh. The second parameter is specific production on annual basis per installed kWp is 1708 kWh/kWp/year. The third parameter is the annual average performance ratio (PR) is 55.2 %. . The detail report is located in **appendix 2** of this thesis.

Table 3.2. Balances and main results

	GlobHor kWh/m^2	GlobalEff kWh/m^2	E_Avail MWh	EUnused MWh	E_miss MWh	E_user MWh	E_load MWh	SolFrac ratio
January	171.5	180.9	57.94	17.17	0.000	38.42	38.42	1.00
February	157.3	156.9	50.08	12.94	0.000	34.70	34.70	1.00
March	191.8	183.4	57.80	17.13	0.000	38.42	38.42	1.00
April	191.2	173.8	54.90	15.52	0.000	37.16	37.18	1.00
May	183.7	158.1	50.49	9.96	0.201	38.22	38.42	0.995
June	172.7	145.0	47.02	7.52	0.000	37.18	37.18	1.00
July	177.8	150.5	49.09	8.58	0.000	38.42	38.42	1.00
August	163.6	144.8	47.31	6.98	0.637	37.76	38.42	0.983
September	168.9	157.8	51.13	12.95	0.601	36.58	37.18	0.984
October	191.2	190.9	61.13	20.10	0.000	38.42	38.42	1.00
November	185.0	196.2	61.79	22.08	0.000	37.18	37.18	1.00
December	167.2	179.1	57.05	16.12	0.000	38.42	38.42	1.00
Year	**2121.9**	**2017.5**	**645.72**	**167.07**	**1.439**	**450.88**	**452.32**	**0.997**

The Balances and main results shown in **Table 3.2** includes variables like the global irradiance on the horizontal plan, effective global irradiance considering soil losses and shading losses. Apart from these variables, DC energy produced by the photovoltaic array, energy supply to the user considering the losses in electrical components, photovoltaic array and system efficiency were also computed. The computed values of each variable mentioned in balances and main results were obtained in terms of monthly and yearly values. For the study location, annual global irradiance on horizontal plane is 2121.9 kWh/m^2 and effective global irradiance after optical losses are 2017.4 kWh/Sq. m and 2017.5 kWh/m^2 respectively. With this effective irradiance, annual DC energy produced from the PV array and annual AC energy load to the user are 450.88 MWh and 452.32 MWh respectively. Annual average energy loss is observed at 1.439 %. This implies just about 0.3 % of energy produce does not satisfy the users needs

Normalized production (per installed kWp)

Figure 3.6 shows the graph of normalized productions per each installed kilowatt power; 378 kWp nominal power. The normalized productions include parameters such as Lu: Unused energy (battery full) =1.21 kWh/kWp/day, Lc: Collection loss (PV-array losses) =1.16 kWh/kWp/day, Ls: System losses and battery charging =0.28 kWh/kWp/day and Yf: Energy supplied to the user =3.27 kWh/kWp/day. These normalized productions are defined by the IEC norms and are standardized variables for assessing the PV system performance. From the graph, the useful energy produced will remain relatively the same through out the year. The highest system losses and collection losses occurs in the period of October, November and December with the month of November recording the highest. It important to know that although PV systems depends on sunlight for electric power production, the heat associated with sunlight affects PV system performance negatively. According to (Ozerdem, 2015), for every 1 ^{O}C of temperature beyond the STC value, the power of the panel is reduced by -0.44 %/K. Collection losses are the losses which occur during conversion of irradiance into power, it is a ratio of how much irradiance is received and how much of that irradiance is converted into power.

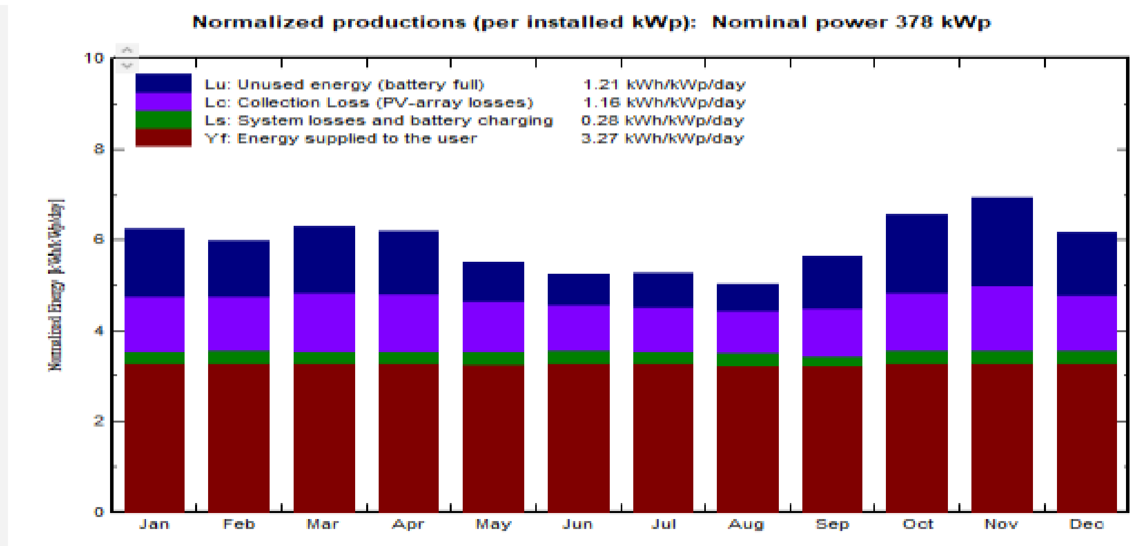

Figure 3.6. Normalized energy production per kWp

Performance ratio

This is a quantity which is defined as the ratio of effective energy produced at the array output with respect to energy produced by an ideal PV system under the same conditions. The performance ratio comprises of system and array losses. From **Figure 3.7,** the performance ratio varies through out the year with an annual performance ratio of 55.2 % for this system. This means that 44.8 % of the total energy produce by the PV modules are either lost or not supplied to the load and battery bank. The lowest performance of the system occurs in the month of June, July and August.

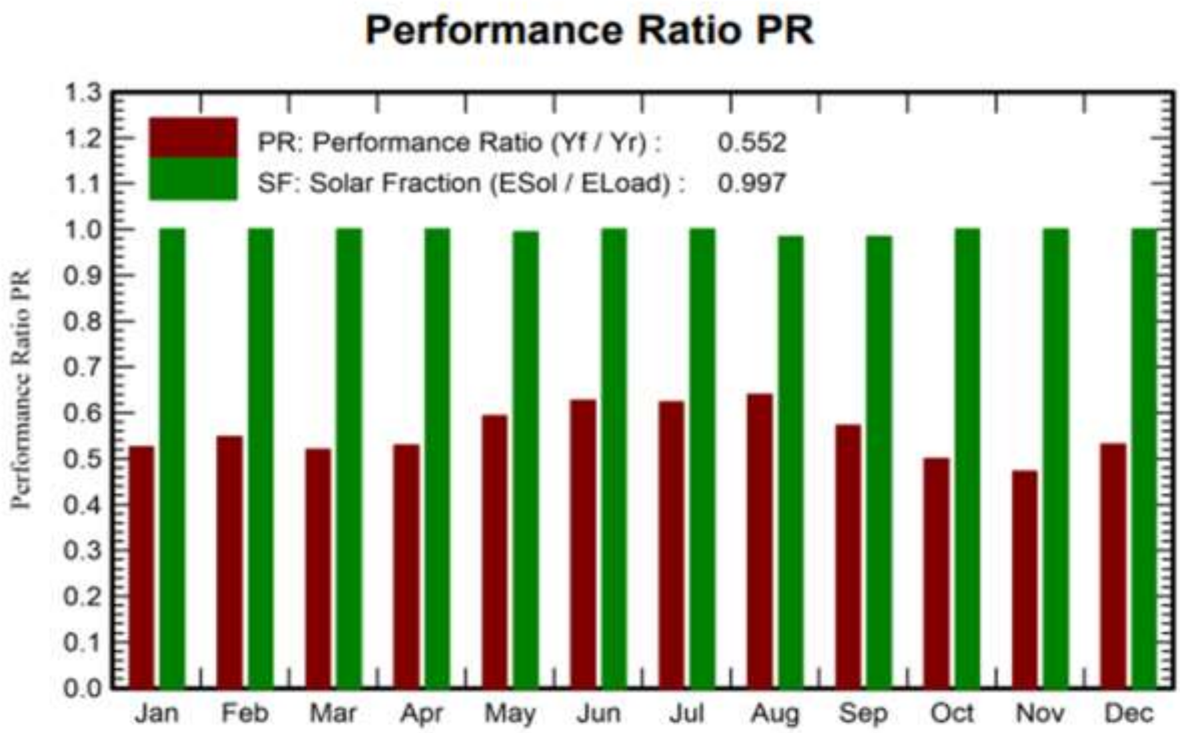

Figure 3.7. Performance Ratio and Solar Fraction

Arrow loss diagram

Arrow loss diagram is obtained from the simulated. This help in analysing the various losses that are to be encountered while installing PV plant or constraints to be considered. Arrow loss diagram is seen in Figure **3.8**. It represents the various losses in the system. Global irradiance on horizontal plane is 2122 kWh/m^2 while the effective irradiance on collector is 2017kWh/m^2. This result in the loss of energy of 0.43 % due to irradiance level. When this effective irradiance falls energy is produced. After the PV conversion, array nominal energy at standard testing conditions (STC) is 197.5 MWh. The efficiency of the PV array at STC is 18.02 % and a yearly energy production at STC of 761.997 MWh, but the actual energy supplied to the user is 450878 kWh yearly, this represents 40.82 % total lost in the PV power plant.

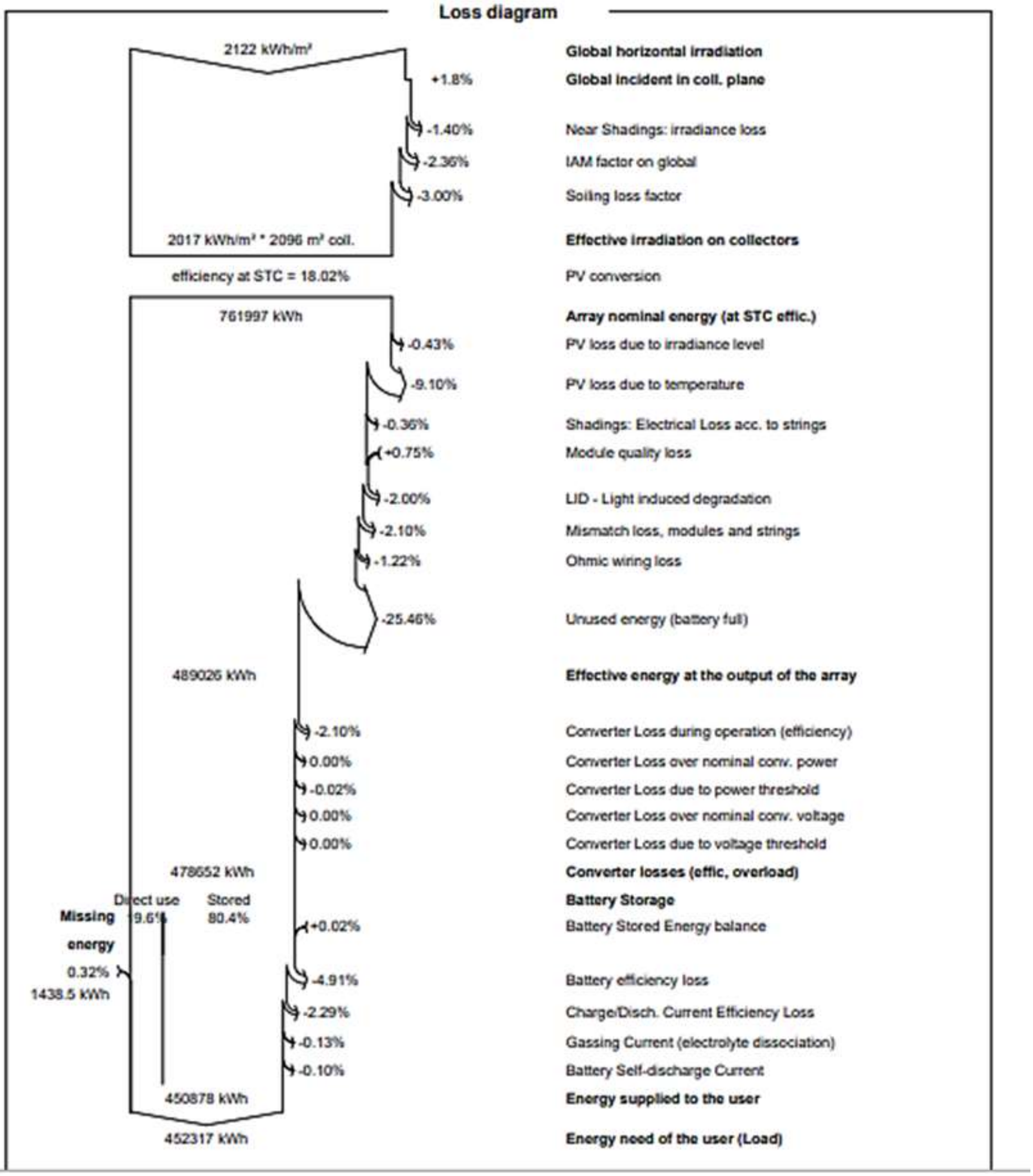

Figure 3.8. Loss diagram of PV system

3.5. ECONOMIC EVALUATION OF THE SYSTEM

PV systems are often considered as a clean energy solution which are environmentally friendly, however, on the other hand, PV systems are also valuable in financial issues with effective design and operation, PV system may pay back its investment and have further profit. To decide the cost and value of a PV system, an economic analysis was conducted. The key result obtained from calculation of the system based on the formulars elaborated in chapter 2 of this work is represented in **Table 3.4.** Using the present-day exchange rate of $1 US dollar to be equivalent to 650 Fcfa the equivalent amount if Cameroon currency was estimated.

Table 3.3. Cost of PV system design

Components	Cost ($)	Cost (frs)
PV array	732 932	476 405 800
Battery bank	85 194.54	55 376 449.7
Charge controller	27 547.91	17 906 138.25
Inverter	146 398.5	95 158 375
Structure cost	198 414.4	128 969 352.6
Installation cost	99 207.19	64 484 676.3
Capital cost	1 289 694	838 300 791.8
Maintenance and operation	25 793.87	16 766 015.84
Battery replacement	270 792	270 792.2423
LCC	2 108 785.516	1 370 710 585
AlCC	75 054.47	48 785 405.71
Unit cost of electricity	0.11/kWh	71.5

From the calculation obtained, the capital cost necessary for the installation of the proposed PV system is roughly eight hundred and thirty eight million, three hundred one thousand and one hundred francs CFA. Additionally, the unit electricity cost using this system was estimated as $ 0.11/kWh which is equivalent to 71.91 frs/kWh. This suggest that electricity produce from PV can be sold at a cheaper price compared to the electrical energy supplied by the national electrical distribution company which billed electricity at 79 frs/kWh. This system is advantageous in the fact that constant electricity is sure with no abrupt blackout and it is also more economical in the long run.

3.6. CARBON-DIOXIDE EMISSION MITIGATION

The conversion of Energy through photovoltaic (PV) system is one of the more reliable and environmentally friendly renewable energy technologies which have the potential to contribute significantly to the development of sustainable energy systems for generation of power. It also plays an important role in CO_2 emissions mitigation. To calculate the total CO_2 emissions mitigated from the present SAPV power system a mathematical computation is carried out. The average intensity of CO_2 emission in Cameroon in 2021 was taken as 0.244 kg/kWh as reported by the world energy statistic. With this value, it is possible to calculate the total mitigation of CO_2 emissions for 20 years using equation (3-1) as follows.

$$CO_2 \text{ emission (kg)} = 0.244 \times E_C \times \text{lifespan of system} \quad (3\text{-}1)$$

Where EC is the total annual electrical energy units consumed as calculated above.

Therefore,

CO_2 emission (kg) = 0.244 × 365 × 1858.79 × 1. This gives a value of 165.54 tons of CO_2 mitigation in one year.

A total of 165.54 tons/year CO_2 emission can be mitigated by the use of PV system and the total mitigated in 20 years is 3 310.88 tons. From these results, it was noticed that, using this system for electricity generation will not only serve the population with basic lightening system but will further reduce the amount of CO_2 release to the environment thereby improving the living conditions of the population, reducing environmental pollution and also a reduction in the emission of greenhouse gases.

GENERAL CONCLUSION

The present research work was centered on the use of solar energy to generate electricity for the Garoua city council. Solar photovoltaic technology is one of the promising renewable energy technologies due to their high reliability and safety. At the same time, it represents a vital and economic alternative to conventional energy. This study presents a complete design and life cycle cost analysis so as to increase electric power deficit in Garoua. More specifically, it consisted of evaluating the energy demand of the said population and determining the environmental benefits of such a project.

The research methodology used in order to achieve the above-mentioned objectives consisted both of quantitative and qualitative approaches. It resulted from field work that the Garoua city although a home to 72 MW hydroelectric power plant, still lacks assess to affordable and reliable energy with most villages in Garoua III municipal councils completely non-electrified. The total load requirement of the selected villages on the assumptions that the demand is constant throughout the years was 1239 kWh. From the simulation studies, at total of 1080 solar panels (monocrystalline) are needed together with a battery bank capacity of 387.25 kAh. A yearly energy production of 761997 kWh was obtained at STC, which correspond to a daily energy production of 2087.66 kWh/d, which is above energy required to satisfy the energy needs of the selected communities. Furthermore, a performance ratio of 55.2 % was obtained indicating the PV power plants will function normally under optimal operations. Undoubtedly, the use of PVsyst software as a tool for solar photovoltaic power plant simulation can be considered a good choice because of its extensive application in research works. A capital cost of 838 301 451 Fcfa is needed to realise this project. The implementation of this project will result in a mitigation of a total of 110.36 tons of CO_2. It could therefore be concluded that technically, environmentally and economically, generation of electricity from solar energy for the population of Garoua city council is feasible, can satisfy the energy needs of the population and poses no danger to the environment.

RECOMMENDATIONS

Based on the results of the research, the following recommendations were made. In general, it is clear that the use of renewable energy sources is an efficient and flexible technology for making electricity both accessible and efficient in both urban and rural areas. However, there is need for the promotion and usage of this energy source especially in the developing areas where the national grid has not yet reach.

- One of the most crucial considerations for the planning of a solar power system in rural areas is the funds necessary for the installation and financial sustainability for operation and maintenance (O&M) of the system. A high capital cost is needed for the acquisition of a solar power plant, but relatively low cost for O&M. Therefore, for easing the financial burden on the initial cost of procuring the system, financial intuitions, both private and public should increase loans accessibility. This can be done by developing innovative mechanisms for loan acquisition.
- The government, through the ministry of Energy and Water Resource in charge of implementing government action in the RE sector needs to formulate proactive and long-term policy, laws and directives for the promotion of renewable energy.
- When evaluating electricity demand for a such projects, estimation should not be limited just for the current demand from the local community but also the potential increase of such demand over the life span of the need to be considered.
- The government should consider integrating rural electrification with renewable energy into other national programs, such as environmental and poverty reduction programs, which can help ease the financial burden of such poor communities.

LIMITATIONS OF STUDY

This work was however handicapped by number of factors.

- ❖ The first limitation of this work is that the energy demand of the population and different households were assumed to remain constant throughout the year which may not be the case in real life as the load profile could change according to season.
- ❖ Also, some of the household refused to take part in the survey to since there were comfortable with their energy situation. It was equally difficult to translate the questionnaire to their native language and needed the help of a translator who could have not explained the question properly.

PERSPECTIVES

This thesis has provided a good foundation for electricity generation from solar energy. However, there is room to improve on this study in future.

- The weekday and weekend load profile of households were not covered in this study. There is a possibility that the load profile of household will differ between weekdays and weekends, and this should be investigated further.
- Furthermore, the electricity consumption data from the questionnaires should be compared with measured data where it is available or combine with such data for a more realistic result.
- It will be interesting and more practical to investigate the effects of dwelling factors and seasonal factors in sizing a SAPV. A study on ways of trimming the peak load profile would also be interesting.
- It will also be interesting to evaluate the payback period of this project since the electricity generated will be sold to the villagers.

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APPENDICES

APPENDIX 1: Dailly energy load of the population estimation form excel

hours	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	wh/hr
LED bulbs in living room	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	50	50	50	50	0	**250**
LED bulbs in rooms	40	0	0	0	40	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	40	40	**240**
LED bulbs in toilets	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	10	0	0	**30**
LED bulbs in kitchen	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	**30**
tv sets	0	0	0	0	0	0	0	0	120	120	120	120	120	0	0	0	0	120	120	120	120	120	120	120	**1440**
electric fans	90	90	90	90	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	90	90	90	90	**900**
phone charger	0	0	0	0	16	16	16	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16	0	0	**96**
Total	**130**	**90**	**90**	**90**	**156**	**76**	**16**	**0**	**120**	**120**	**120**	**120**	**120**	**0**	**0**	**0**	**0**	**120**	**180**	**286**	**276**	**326**	**300**	**250**	**2986**
number of household																									
415	53950	37350	37350	37350	64740	31540	6640	0	49800	49800	49800	49800	49800	0	0	0	0	49800	74700	118690	114540	135290	124500	103750	1239190

APPENDIX 2: Question Administered to the population

survey

I am called **ATEAFAC NJIKENG**, a Level 5 student of the National Advanced School of Public Works, Yaoundé. I am in my final year and my research project concerns "**Potential of Electricity generation from solar energy for the Garoua City Council**". The objective of this survey is to obtain adequate information as regards the electricity situation of the Garoua City Council. This information is extremely important to effectively design and cost a solar power plant for the council so as to resolve the energy deficit in the Garoua city council.

NB: All information gotten will be exploited to realize my thesis and are very confidential.

Section A: Control and supervision

Q1. Name of Quarter ____

Q2. Date of Interview

____

Q3. Result of answer question.

1 – Filled, 2 – partially filled, 3 – no response, and 4 – other

Section B: Identification of household

Q1. Name of respondent ____

Q2. Origin of respondent ____

1 – Adamawa, 2 – East, 3 – Centre, 4 – Littoral, 5 – North,

6 – Far-North, 7 – North-West, 8 – West, 9 – South-West, 10 – South, 11- other (precise)

Q3. Sex of respondent

1-Male, 2- femaleQ3. Age range of respondent

18-25 ☐ 25-50 ☐ 50 and above ☐

Q4. Professional situation of respondent:

1 – Unemployed, 2 –employed, 3 – student, 4 – others (precise)

____

Q5. If employed, what work do you do?

1-Trader, 2- farmers, 3- civil servants, 4 private sector, 5 others (precise)

Q6. What is your monthly income?

1 – 20.000-40.000, 2 – 40.000-60.000, 3 – 60.000-100.000, 4 – 100.000 and above

Section C: Household and equipment

Q1. What type of energy do you use for lighting?

1 – electricity, 2 – kerosene lamp, 3 – diesel or petrol generator, 4 Biomass (firewood), 5- others (precise)---

Q2. How much do you spend on energy sources monthly?

1 – 1000-5000, 2 – 5000-7000, 3 – 7000-10.000, 4 – 10.000-15.000, 5 – 15.000 and above

Q3. Are you satisfied with the energy situation in your locality?

1 – yes, 2 – no 3- I do not know

Q4. What electrical appliances will you buy if you had electricity?

Q5. What are the problems faced as a result of no electricity in your locality?

Q6. According to you, what solution to generate electricity for your locality?

Thank you for your contributions

APPENDIX 3 : PVsyst simulation report

PVSYST PHOTOVOLTAIC SOFTWARE

Version 7.1.8

PVsyst - Simulation report

Stand alone system

Project: thesis work new

Variant: New simulation variant one

Stand alone system with batteries

System power: 378 kWp

Garoua - Cameroon

Author

PVsyst V7.1.8
VC1, Simulation date:
26/09/22 14:09
with v7.1.8

Project: thesis work new

Variant: New simulation variant one

Project summary

Geographical Site		**Situation**		**Project settings**	
Garoua		Latitude	9.30 °N	Albedo	0.20
Cameroon		Longitude	13.40 °E		
		Altitude	189 m		
		Time zone	UTC+1		

Meteo data
Garoua
Meteonorm 8.0 (1986-2005), Sat=100% - Synthetic

System summary

Stand alone system — **Stand alone system with batteries**

PV Field Orientation		**Near Shadings**		**User's needs**	
Fixed plane		According to strings		Daily profile	
Tilt/Azimuth	15 / 0 °	Electrical effect	100 %	Constant over the year	
				Average	1239 kWh/Day

System information

PV Array		**Battery pack**	
Nb. of modules	1080 units	Technology	Lead-acid, sealed, Gel
Pnom total	378 kWp	Nb. of units	288 units
		Voltage	48 V
		Capacity	41640 Ah

Results summary

Available Energy	645718 kWh/year	Specific production	1708 kWh/kWp/year	Perf. Ratio PR	55.21 %
Used Energy	450878 kWh/year			Solar Fraction SF	99.68 %

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General parameters

Stand alone system — **Stand alone system with batteries**

PV Field Orientation

Orientation
Fixed plane
Tilt/Azimuth 15 / 0 °

Sheds configuration
Nb. of sheds 27 units
Sizes
Sheds spacing 5.00 m
Collector width 3.93 m
Ground Cov. Ratio (GCR) 78.6 %
Shading limit angle
Limit profile angle 40.5 °

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar separate

Near Shadings
According to strings
Electrical effect 100 %

User's needs
Daily profile
Constant over the year
Average 1239 kWh/Day

Hourly load	0 h	1 h	2 h	3 h	4 h	5 h	6 h	7 h	8 h	9 h	10 h	11 h	
	53.9	37.4	37.4	37.4	64.7	31.5	6.6	0.0	49.8	49.8	49.8	49.8	kW
	12 h	13 h	14 h	15 h	16 h	17 h	18 h	19 h	20 h	21 h	22 h	23 h	
	49.8	0.0	0.0	0.0	0.0	49.8	74.7	118.7	114.5	135.3	124.5	103.8	kW

PV Array Characteristics

PV module
Manufacturer Jinkosolar
Model JKM 350M-72
(Original PVsyst database)
Unit Nom. Power 350 Wp
Number of PV modules 1080 units
Nominal (STC) 378 kWp
Modules 270 Strings x 4 In series
At operating cond. (50°C)
Pmpp 341 kWp
U mpp 141 V
I mpp 2408 A

Controller
Manufacturer Victron
Model SmartSolar MPPT 250/100 48V
Nb. units 54 units
Technology MPPT converter
Temp coeff. -2.7 mV/°C/Elem
Converter
Maxi and EURO efficiencies 99.0 / 97.0 %

Total PV power
Nominal (STC) 378 kWp
Total 1080 modules
Module area 2096 m²
Cell area 1846 m²

Battery
Manufacturer BAE Secura
Model BAE Secura Solar 24 PVV 4560
Technology Lead-acid, sealed, Gel
Nb. of units 12 in parallel x 24 in series
Discharging min. SOC 16.0 %
Stored energy 1679.7 kWh
Battery Pack Characteristics
Voltage 48 V
Nominal Capacity 41640 Ah (C10)
Temperature Fixed 20 °C

Battery Management control
Threshold commands as Battery voltage
Charging 54.7 / 50.1 V
Corresp. SOC 0.90 / 0.75
Discharging 46.2 / 48.9 V
Corresp. SOC 0.16 / 0.45

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Array losses

Array Soiling Losses
Loss Fraction 3.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 0.65 mΩ
Loss Fraction 1.0 % at STC

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.4 % at STC

LID - Light Induced Degradation
Loss Fraction 2.0 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
ASHRAE Param: IAM = 1 - bo(1/cosi -1)
bo Param. 0.05

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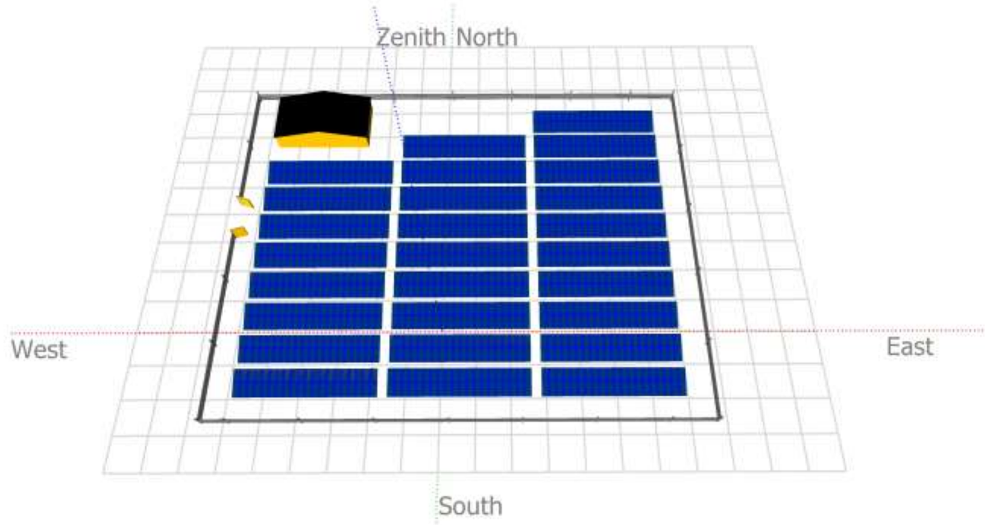
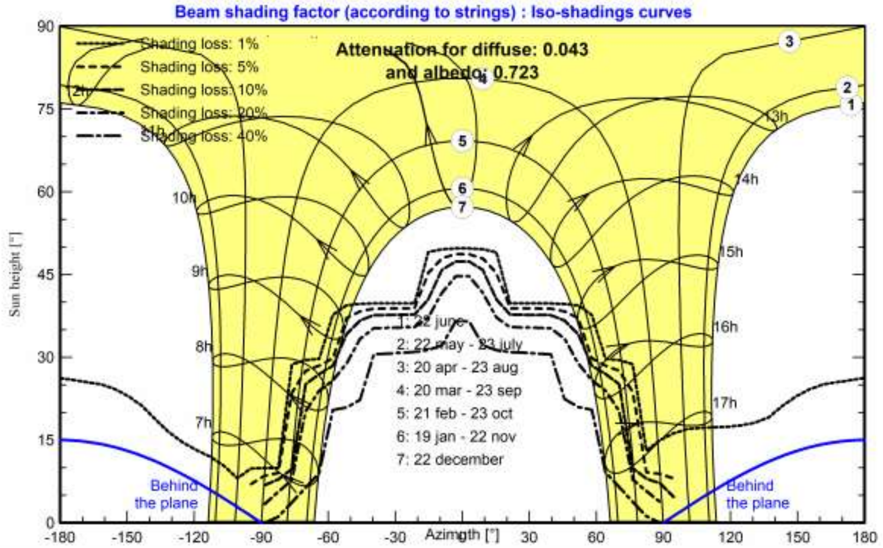
Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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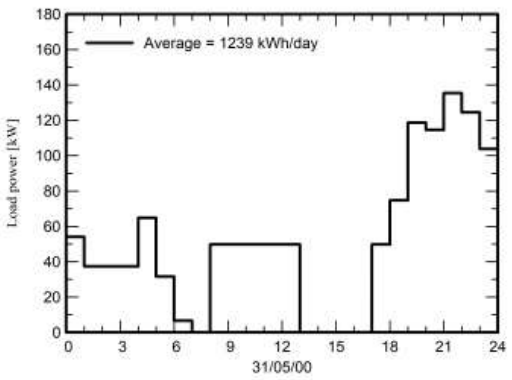
Detailed User's needs

Daily profile, Constant over the year, average = 1239 kWh/day

Hourly load	0 h 53.9	1 h 37.4	2 h 37.4	3 h 37.4	4 h 64.7	5 h 31.5	6 h 6.6	7 h 0.0	8 h 49.8	9 h 49.8	10 h 49.8	11 h 49.8	kW
	12 h 49.8	13 h 0.0	14 h 0.0	15 h 0.0	16 h 0.0	17 h 49.8	18 h 74.7	19 h 118.7	20 h 114.5	21 h 135.3	22 h 124.5	23 h 103.8	kW

Daily profile



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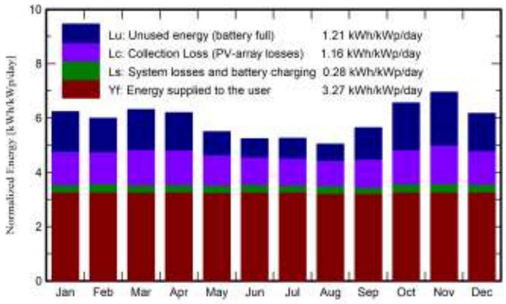
Main results

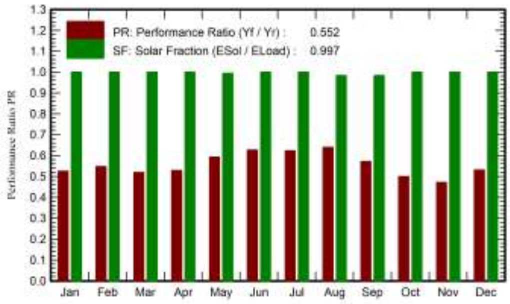
System Production

Available Energy	645718 kWh/year	Specific production	1708 kWh/kWp/year
Used Energy	450878 kWh/year	Performance Ratio PR	55.21 %
Excess (unused)	167066 kWh/year	Solar Fraction SF	99.68 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	0.5 %	Cycles SOW	80.4 %
Missing Energy	1439 kWh/year	Static SOW	90.0 %
		Battery lifetime	5.1 years

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	171.5	180.9	57941	17174	0.0	38416	38416	1.000
February	157.3	156.9	50083	12943	0.0	34698	34698	1.000
March	191.8	183.4	57796	17134	0.0	38416	38416	1.000
April	191.2	173.8	54900	15516	0.0	37177	37177	1.000
May	183.7	158.1	50485	9965	200.9	38215	38416	0.995
June	172.7	145.0	47020	7520	0.0	37177	37177	1.000
July	177.8	150.5	49086	8576	0.0	38416	38416	1.000
August	163.6	144.8	47309	6984	636.8	37779	38416	0.983
September	168.9	157.8	51128	12949	600.8	36576	37177	0.984
October	191.2	190.9	61126	20105	0.0	38416	38416	1.000
November	185.0	196.2	61794	22078	0.0	37177	37177	1.000
December	167.2	179.1	57050	16123	0.0	38416	38416	1.000
Year	2121.9	2017.5	645718	167066	1438.5	450878	452317	0.997

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

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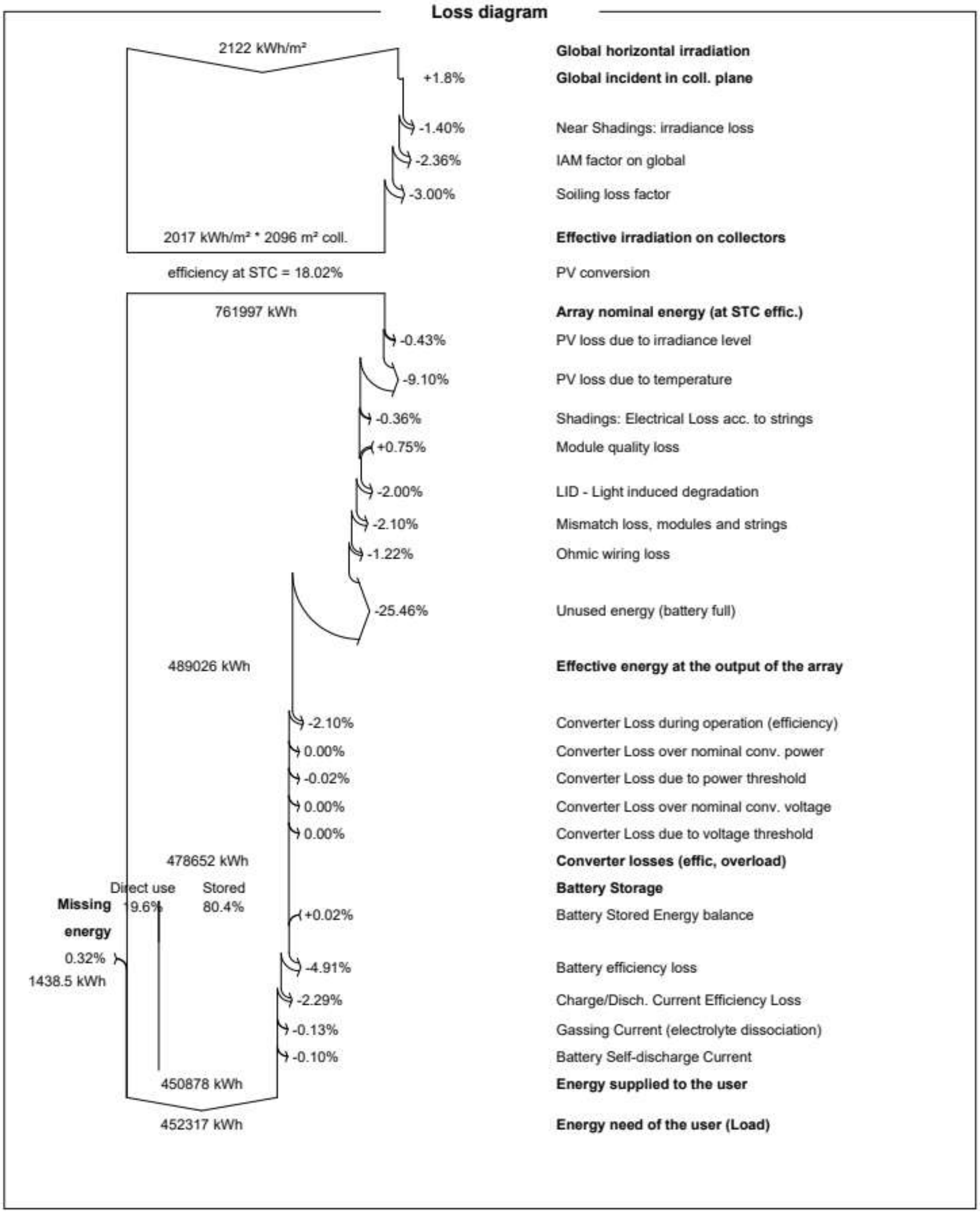
Loss diagram



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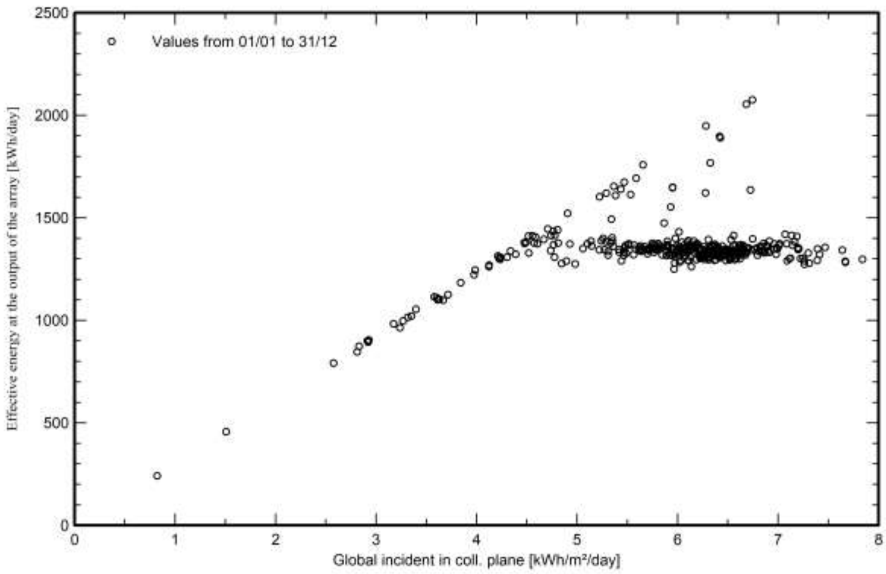
Special graphs

Daily Input/Output diagram



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