Title of the Project: **ASSESSMENT OF ADOPTION OF SOLAR ENERGY IN RURAL PERI-URBAN AND URBAN AREA. Case study Rwanda**

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MASTERS OF SCIENCE in Renewable Energy

Supervisor's Names: Dr Venant KAYIBANDA

October, 2020

**DECLARATION**

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

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**Date: 20th October, 2020**

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**Date: 20th October 2020**

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**May God bless you all!!**

**ABSTRACT**

Currently, use of solar technology as form of renewable energy has been developed in different area of human being such as electrification, heating, medicine etc. Research works are significantly being conducted for exploration of possible use of Solar Energy Technology. In Rwanda also research works in this area are being done but there is not reliable information about how Rwandan people are adopting the use of solar energy. The gap between demand and supply encourage different organization to obtain alternative for sustainable supply of power. The improvement of solar energy technologies and knowledge is on of the solution to fill that gap.

The objectives of this dissertation in assessment of adoption of Solar Energy in rural, pre-urban and urban area was the identification of factors that positively and negatively influence the adoption of the solar energy in three sectors chosen in rural, peri urban and urban respectively. Also comparing the adoption of solar energy in chosen habitat category was one of the objectives of this study. To achieve the objectives of this work, a qualitative research approach was used. A well structured interview has been used as the method. From different findings from this study, the adoption of solar energy is high in rural area due to absence of on grid electricity. This is the answer by considering those who use solar PV however the adoption is high in urban where most of people in urban use solar water heater and not use mostly PV because of accessing on grid electricity easily.

Positive factors and negatives factors that influence the adoption of solar energy have been identified during this study. Among factors that negatively influence the adoption of solar energy, the 'affordability of solar energy' and the 'insufficient output' were the most mentioned during this study. On the other hand, the willingness to protect the environment, the fact that energy bill is paid once for all, and the absence of on-grid electricity have been the most mentioned factors that positively influence the adoption of solar energy. With different views from households and suppliers, some recommendations were formulated to help the amelioration of adoption of solar energy. The two most evoked recommendations are the improvement of solar energy storage and the reduction of solar energy systems' cost.

***Key words**: Renewable energy, solar energy, adoption, factors, households.*

# ACRONYMS

MIC: Middle Income Country

HIC: High-Income Country

NST1: National Strategies for Transformation one

EDPRS: Economic Development and Poverty Reduction Strategies

GDP: Growth domestic product

DC: Direct Current

AC: Alternative Current

MW: Mega Watt

REG: Rwanda Energy Group

PV: Photovoltaic

Gt : Gigatonnes

$CO_2$: carbon dioxide

H: Hydrogen

He: Helium

CSP: concentrating solar power (

$VT$: thermal voltage

$Rs$: Series resistances

$R_{p:}$ Parallel resistances

**KWh :** Kilo watt hour

Rw: Rwanda

NGO: Non Government Organization

Nr: Number

EPD : Energy Private Developers

**kWh:** Kilo watt hour

**$H_2O$:** Water

**L:** Litre

**$m^3$:** Cubic metre

**Kg:** Kilogram

**$m^2$:** Square metre

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# 1 Introduction

Rwanda is one of the African countries. It is a small and locked, it has population estimated at is estimated at **12,952,218,** the population density in Rwanda is 525 per $Km^2$ (1,360 people per $mi^2$) and the total land area is 24,670 Km2 (9,525 sq. miles)[1]. It borders the far larger and richer Democratic Republic of Congo, as well as its closest East African neighbors, Tanzania, Uganda, and Burundi. Rwanda now aspires to reach Middle Income Country (MIC) status by 2035 and High-Income Country (HIC) status by2050. This aspiration will be carried out through a series of seven-year National Strategies for Transformation (NST1), underpinned by detailed sectoral strategies that are aimed toward achievement of the Sustainable Development Goals. The NST1 came after the implementation of two, five-year Economic Development and Poverty Reduction Strategies EDPRS (2008-2012) and EDPRS-2 (2013-2018), under which Rwanda experienced robust economic and social performances. Growth averaged 7.5% over the decade to 2018, while per capita growth domestic product (GDP) grew at 5% annually[2] . Among the keywords to the development of Rwanda, Sustainable development of Energy sector is one of them. Rwanda is Aiming in the development of energy but also by keeping the climate safe. This will be possible by promoting the renewable energy. Rwanda in the way of reaching its goal of 100% of electrification [3], where the share of grid extension in 2024 will reach 52% of on-grid connections in 2024 of all Rwanda in the National Electrification Plan, including 31% of already existing connections in April, The remaining 21% will be both fill-in connections in already electrified villages and extension of the grid to new villages in 2024. Off-grid connections will represent 48% of the universal electrification target, of which Grid Standard Microgrid serving a whole village would represent 10%, and DC Solar Kits or AC Stand-Alone Systems would account for 38%, of which 7 % are villages where coexistence of solar kits and microgrid could be a choice to consider at the implementation phase, 21% are in villages where only SAS is the recommended option, 10% are off-grid customers already electrified in April, 2019[3].

According to the $7^{th}$ international conference on modern power system in 2017, they showed that the annual solar energy potential of the earth was 23.000TWy. And 1,600TWy should be the word energy consumption for 100 years. This computed with the yearly consumption in 2009 [4] .The use of green and clean solar energy is not new discovery of the scientist of our days. The sun was used in diverse scopes since a lot of centuries. therefore the history of solar energy conversion is long, various and exciting[4].

According to the report done by international renewable agency shows that there is a very good future of photovoltaic where they said that there is a huge role of solar photovoltaic (PV) in the transformation of the global energy [5]. That future is based on electrifying the world but also in playing a huge role in climate change where they showed that among all low-carbon technology option, accelerated deployment of solar PV alone can lead to significant emission reduction of 4.9 Gigatonnes of carbon dioxide (Gt CO2) in 2050 representing 21%of the total emission mitigation potential in the energy sector[5]. Solar energy is the energy produced by capturing heat and light from the Sun. Technology has provided a number of ways to utilize this abundant resource. That technology is considered as green technology because it does not emit greenhouse gases. Rural areas are locations far from the most lived and often lack of electrification. Solar energy found as solution to that problem. The attraction of these resources lies in the abundance and the advantages most of them as green energy. Many of the rural area in lack of grid power energy have a high potential of renewable energy with solar energy in abundant. The report of the $7^{th}$ international conference on modern power system in 2017 done by IRENA showed that the annual solar energy potential of the earth was 23.000TWy. And 1,600TWy should be the word energy consumption for 100 years. This computed with the yearly consumption in 2009 [4] .

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## 1.1 Solar Energy in Rwanda.

Energy from the sun is called solar energy means that the solar energy is energy from sunlight. Solar energy is a type of renewable energy; it will never run out and sometimes called radiant energy. These are different kinds of radiant energy emitted by the sun. The most important is light infrared rays, Ultraviolet rays, and X-Rays. Today, satellite data shows that the territory of Rwanda is in the global zone where the daily global radiation (annual average) is between 4 and 6 kWh/m²/ day. The current average of solar radiation is about 4.5 kWh / m² / day for most of the country and it sunshine time per day is 8 hours, which make solar energy

in Rwanda economically viable. The Government of Rwanda is targeting 100% electricity access by 2024 promoting the use of renewable energy, mostly on-grid and off-grid solar PV systems.

Two solar PV plants namely GIGAWATT Global Solar Power (8.5 MW) and Jali Solar Power (0.25 MW) located in Rwamagana and Gasabo districts respectively are connected to the National Grid [8]. Households far away from the planned national grid coverage are encouraged to use Solar Photovoltaics (PVs) to reduce the cost of access to electricity. Rwanda's total on-grid installed solar energy is 12.08 MW.[6]

## 1.2 Access to Power in Rwanda

Rwanda is targeting to reach 100% of electrification by 2024. The following figure 3 and 4 respectively shows the current evolution of installed capacity and the evolution of connection.

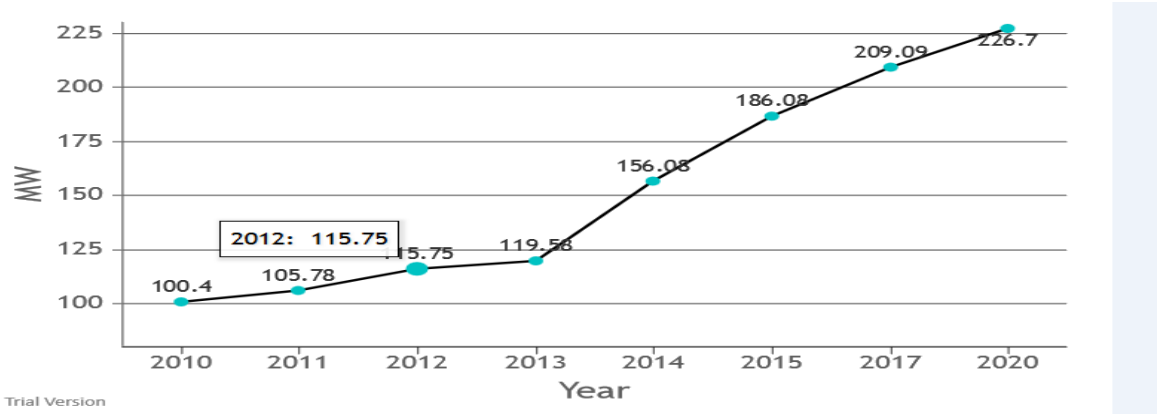


Figure 1: Evolution of the installed capacity in MW [7]

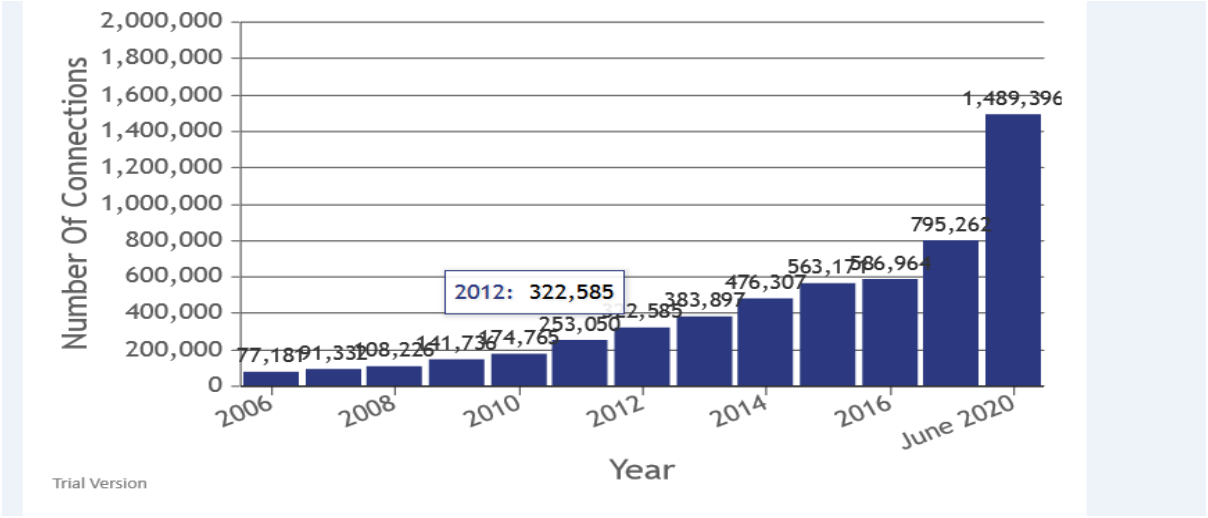


Figure 2: *Evolution Of connection [7]*

## 1.3 Background and Motivation

The sun is a hot sphere of gas whose internal temperatures reach over 20 million degrees Kelvin due to nuclear fusion reactions at the sun's core which convert Hydrogen (H) to Helium (He). The radiation from the inner core is not visible since it is strongly absorbed by a layer of Hydrogen atoms closer to the sun's surface. Heat is transferred through this layer by convection.[8] The sun provides two forms of energy, heat and light, which can be converted to electricity for further transportation and usage. These two forms of energy can be harnessed by two primary methods of cultivation using concentrating solar power (CSP) or photovoltaic (PV). CSP system is an indirect method of solar energy cultivation. The system concentrates solar thermal energy (heat) onto a medium which is used as a source of energy by an electrical power generator. A classical CSP system uses mirror to concentrate solar thermal energy onto water which generates steam and drive a turbine to generate electricity. PV system, on the other hand, generates electricity directly via photoelectric effect [9] There are two basic setups for small scale PV arrays: Off grid systems which utilize a charging system and battery for backup power, and grid connected systems which utilize the grid for backup power, as well as feeding excess power back into the grid.

## 1.4 Basic of Photovoltaic cell

PV cells are made up of single crystalline or polycrystalline silicon. The efficiency ranges from 11-15%. They are expensive in cost due to thickness. But with the recent development of thin film material like copper indium selenide and cadmium telluride, the cost was greatly reduced with considerable efficiency [10]

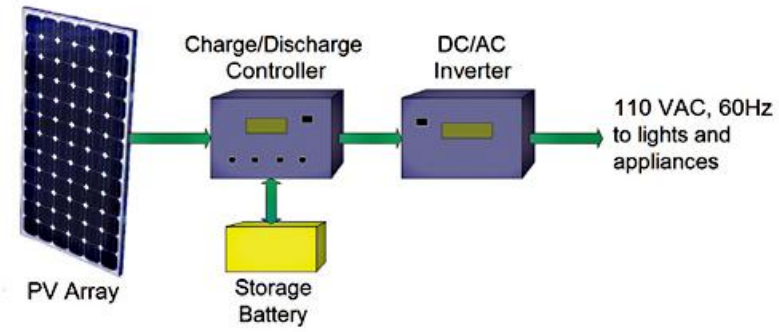


*Figure 3:* Off grid PV system set up [11]

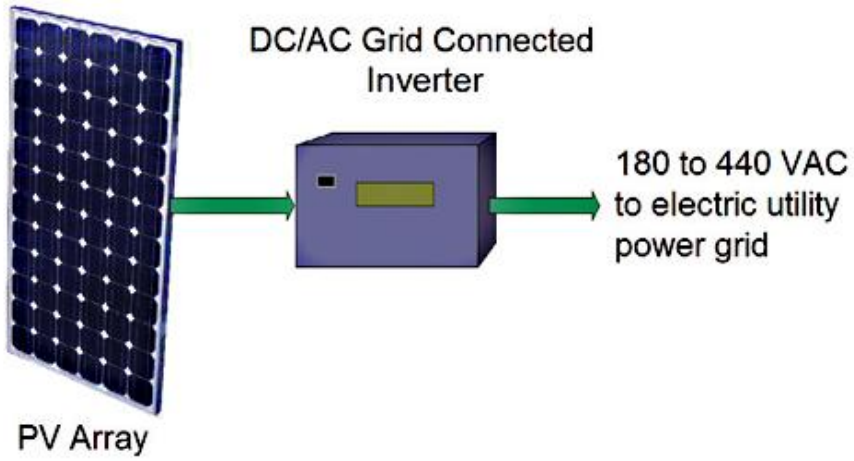


*Figure 4 :* Grid connected system [12]

## 1.5 Growth of Solar PV

In 2014 PV had a global installed capacity of 177 GW. It had a growth rate of 55.9 % between 2002 and 2012.The highest annual growth rate of 65.1 % was achieved between 2011 and 2012. It is projected that by 2030 solar PV will contribute 5 % of the total electrical energy demand and 11 % by 2050. [13]

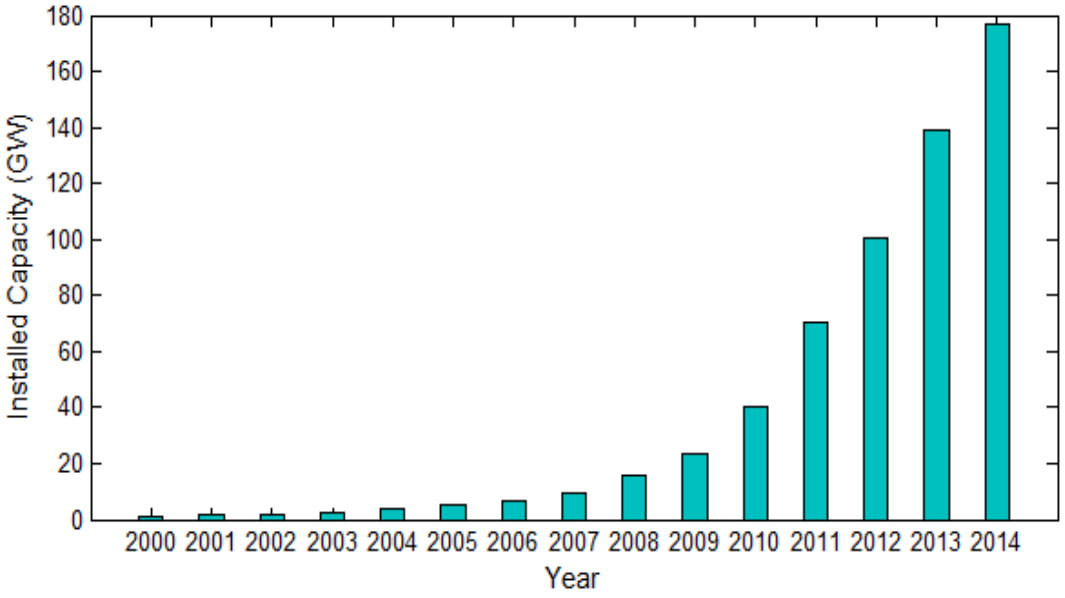


Figure 5: Global installed PV capacity between 2000 and 2014[13]

## 1.6 Problem Statement

Rwanda is in the process of reaching 100% of electrification where an adequate and reliable power supply is essential. The supply is insufficient and unreliable for may population in Rwanda. Today the cumulative connectivity rate is 56.7% of Rwandan households including 41.3% connected to the national grid and 15.4% accessing through off-grid systems (mainly solar). Solar energy can be very interesting to rural area as they have many difficulty to access the electricity from the grid but according to its advantages and its abundant and access it has been used in rural area as well as in peri- urban and urban area. The stand alone photovoltaic has been installed in rural area and solar thermal heaters are used in many peri-urban and urban areas in Rwanda. The government has been even set some facilitation to access those sources of energy from the sun as facilitating people in paying but the expected number to access is still low. Research works are significantly being conducted for exploration of possible use of Solar Energy Technology. In Rwanda also research works in this area are being done but there is not reliable information about how Rwandan people are adopting the use of solar energy. Lack of knowledge in drivers of adoption or non-adoption of solar energy is a big problem to improvement of solar energy in Rwanda, particularly considering the differing technical, financial, environmental and social contexts. This dissertation will identify the barriers and drivers of the adoption and non adoption of solar energy system among home owners and the compare the adoption of solar energy in chosen habitat categories.

## 1.7 Study Objectives

### 1.7.1 General Objective

The main objective of this research work is to assess and determine the factors that influence the adoption of solar energy in rural area, pre-urban and urban area in Rwanda.

### 1.7.2 Specific Objectives

The specific objectives of this work are:

- Compare solar energy adoption in urban peri- urban and rural areas.
- Determine the factors that positively influence the adoption of solar energy in urban, peri-urban and rural area.
- Determine the factors that negatively influence the adoption of solar energy in urban, peri-urban and rural area.
- Draw relevant conclusion and recommendations to guide future research and the energy sector in Rwanda.

## 1.8 Study Scope

The scope of this study is tending to determine the factors that influence the adoption and non adoption of solar energy in rural, peri-urban and urban area. Where in rural area, Muhanga district, Rongi sector have been assessed, in peri urban: Bugesera district, Juru Sector and in urban area, Kicukiro district, kagarama sector.

### 1.8.1 Geographical scope

The study was carried out in Muhanga District Rongi Sector, Bugesera district Juru sector and Kicukiro district Kagarama Sector. Muhanga is one of 8 Districts of Southern Province; it has 12 Sectors, 63 cells, and 331 Villages. It covers 647,7km$^2$. The population of Muhanga District is 318,965 peoples, The household is 69,809 formed by Male 155,193 (49%) and Female 163,772 (51) Muhanga District boundaries are North: Gakenke District, South: Ruhango District, East: Kamonyi District, West: Ngororero District. Muhanga District is divided into two parties: The urban area and rural area. The urban Area situated in Nyamabuye secotor and small part of Shyogwe and Cyeza Sector. The rural area is located in Muhanga, kabacuzi, Kibangu, Kiyumba, Nyabinoni, Nyarusange, Rongi, Mushishiro, Rugendabari sectors. The economy of Muhanga District is based on Agriculture of coffee, rice, cassava, vegetables and cereals. [14]

Bugesera District is one of the seven Districts that make up the Eastern province of Rwanda. It neighbors the city of Kigali and is at a frontier to the Republic of Burundi. It is from this background that Bugesera is positioned as a niche for development due to its proximity to the capital city Kigali and the neighboring Burundi. It covers a total surface of 1337km$^2$, is composed of 15 sectors, 72 cells and 581 Villages with a total population of 363,339 people, where 177,404 are males and 185,935 are females. Its population AGR( Annual Growth Rate) is 3.1% with a population density of 282 people per km$^2$[15].

Kicukiro is a district of Kigali Province, is dived into 10 sectors: Gahanga, Gatenga, Gikondo, Kagarama, Kanombe, Kicukiro, Kigarama, Masaka, Niboye and Nyarugunga. Kagarama is considered as the capital of Kicukiro district. Kicukiro district has total area 167km$^2$(64sqmi). It has 318,564 of population, density 1,900/km$^2$ (**Appendix 4**)

## 1.9 Significance of the Study

Electrical power plays a significant role in development of the people's live and standards and accelerating the economic. Significant investments have been made in energy sector to improve electricity access in all the country where the target of the government ware to have 100% of electrification by 2020 [3]. Instead of using the only national grid that may not be accessible by rural areas, solar energy has been in the top of other type of energy which can be used. This approach will serve as an economical and reliable solution to reach the target. The rural area was the targeted place by the use of solar energy but according to its advantages, it has even in peri urban and urban areas have been encouraged to use it. With this study the number of users of solar energy will be improved which will lead to the climate change, development of different area by installing new business which use solar energy, people can get facilitation and get the chance to use solar energy.

### 1.9.1 Expected Outcome of the Study

There is a policy of improving renewable energy in Rwanda but still there is a problem of assessing its adoption, this study will come out with better understanding of the drivers of solar energy adoption which will help energy sectors in Rwanda. The output of this work will lead to Optimal Prioritization of solar Energy use in Rwanda. It will help to demonstrate how people are adopting to this system, factors and obstacles influencing on the use of solar energy and the way motivating the use of solar energy

# 2 Literature review

At present, Rwanda is targeting to reach 100% of electrification in 2024 (NST1, 2017)[16]. Rwanda is endowed with natural energy resources including hydro, solar, and methane gas. It currently has 218MW Of Installed generation capacity where 98 MW is for Hydroelectricity, 103MW is for Thermal and the Solar has only 12[17]. According to the international energy agency (IEA),Rwanda is estimated at 30% (12% in rural areas and 72% in urban areas) [16] . With a potential of 4.5 kWh per m2 per day and approximately 5 peak sun hours, solar energy has a huge potentiality in Rwanda. Currently, Rwanda's total on-grid installed solar energy is 12.08 MW originating from 4 solar power plants namely Jali power plant generating 0.25MW, Rwamagana Gigawatt generating 8.5 MW and the Nasho Solar plant generating 3.3 MW[18]. The Government of Rwanda intends to increase the number of solar power therefore the evaluation of factors that influence the use of solar energy and Those that are in base of not use it will help the government in reaching its goal of improving solar power plants.

## 2.1 Basic concepts

The method of obtaining electricity from sunlight is referred to as the Photovoltaic method. This is achieved using a semiconductor material.

The other form of obtaining solar energy is through thermal technologies, which give two forms of energy tapping methods.

- The first is solar concentration, which focuses solar energy to drive thermal turbines.
- The second method is heating and cooling systems used in solar water heating and air conditioning respectively.

The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

- **Solar system components are:**

  - ✓ **Solar modules**

Solar panels are the core of solar power system and they are the most valuable part in solar power system. It transfer the solar energy to power or to storage in the batteries

  - ✓ **PV Controller**

PV Controller is to control the working state of the whole system. It is also used in protection of battery form overcharged and discharged. It is again used in temperature compensation.

  - ✓ **Batteries**

Batteries are used to store the power generated by solar modules and discharge when needed. They use lead acid or colloidal battery. There are small or micro systems which can use a nickel hydrogen battery, a nickel cadmium battery or a lithium battery

## 2.2 Generation of solar energy and Definitions of some key terms

The sun is a star. It is the largest object in our solar system and one of the larger stars in our galaxy. The source of energy in the Sun is at its core where hydrogen is converted to helium in a thermonuclear reaction. This energy travels from the core to the surface of the Sun and is released into space primarily as light. The Sun is the most prominent feature in our solar system. It is the largest object and contains approximately 98% of the total solar system mass. The sun is 4.6 billion years old. It is largely composed of hydrogen and helium. The sun is about 110 times bigger than the earth. One hundred and nine Earths would be required to fit across the Sun's disk, and its interior could hold over 1.3 million Earths. The Sun's outer visible layer is called the photosphere and has a temperature of 6,000°C (11,000°F). [19]

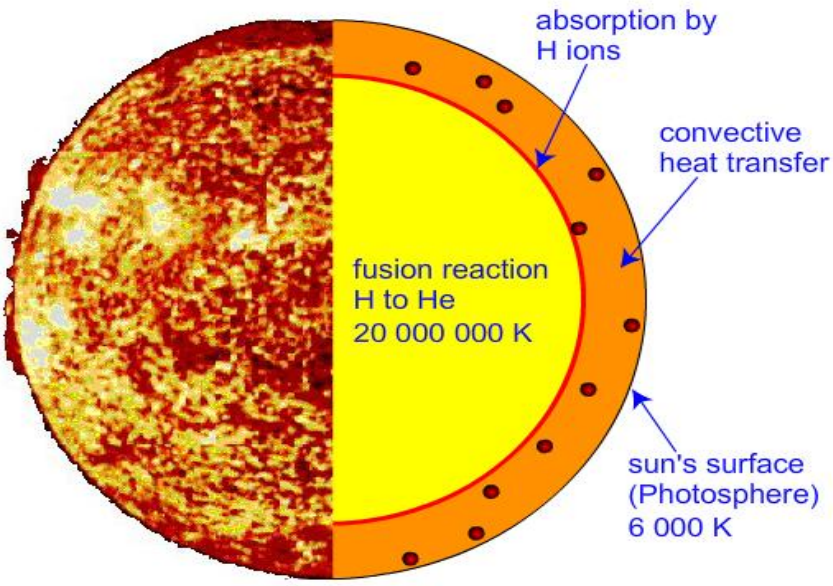


*Figure 6 :* solar energy production [20]

Energy is produced in the sun by continuous fusion reactions in which 4 nuclei of Hydrogen fuse in series of reactions.

4 H → 2 He + 2 P + 1 Ne

2He release 3.5 MeV of energy

1 Ne releases 14.1 Million eV

Total energy released from 4 nuclei of Hydrogen= 17.6 MeV. Other reaction is combination of 2 Isotopes of Hydrogen (Deuterium (D) and Tritium (T). Chemical reaction is D+T = He + 1 Ne

H: 1 Electron, 1 Proton

D: 1 Electron, 1 Proton, 1 Neutron

T: 1 Electron, 1 Proton, 2 Neutrons[20]

## 2.3 PV Cell, Module and Array Models

The array by itself does not constitute the PV power system. A complete PV power system consists of:

- A structure to mount it.
- A sun tracker to point the array to the sun (optional).
- Various sensors to monitor system performance.
- Power electronic components that accept the DC power produced by the array, charge the battery, and condition the remaining power in a form that is usable by the load.

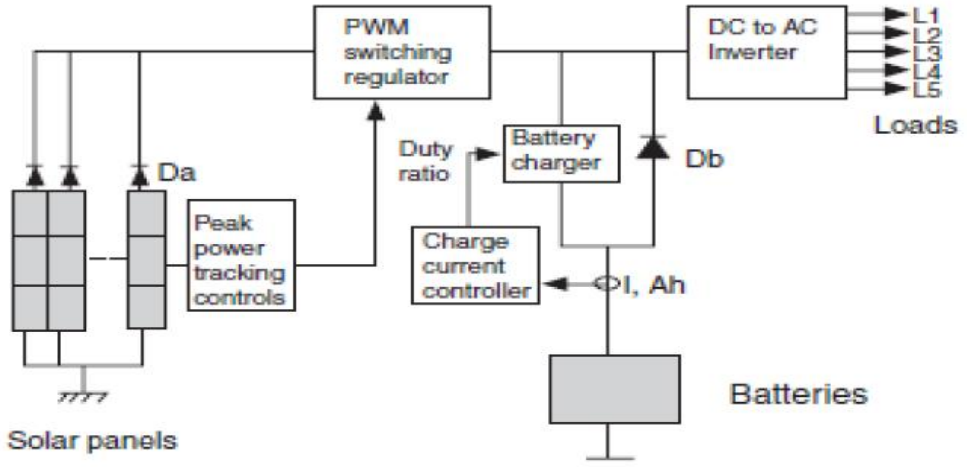


Figure 7 : Components of a PV power system[8]

### 2.3.1 Solar PV Generation

In solar PV, the sun's higher frequency radiation (visible and ultra violet) is captured by an array of semiconductor photovoltaic cells which convert the radiant energy directly to electricity. The insolation reaching an array depends on its position on the earth, its orientation, time and weather. The energy captured is directly proportional to the area of the sun's energy front intercepted by the collector. The basic unit of a solar PV system is the solar cell. A number of solar cells connected in series and parallel is called a PV module. A number of solar modules connected in series and parallel is called a PV array.[21]

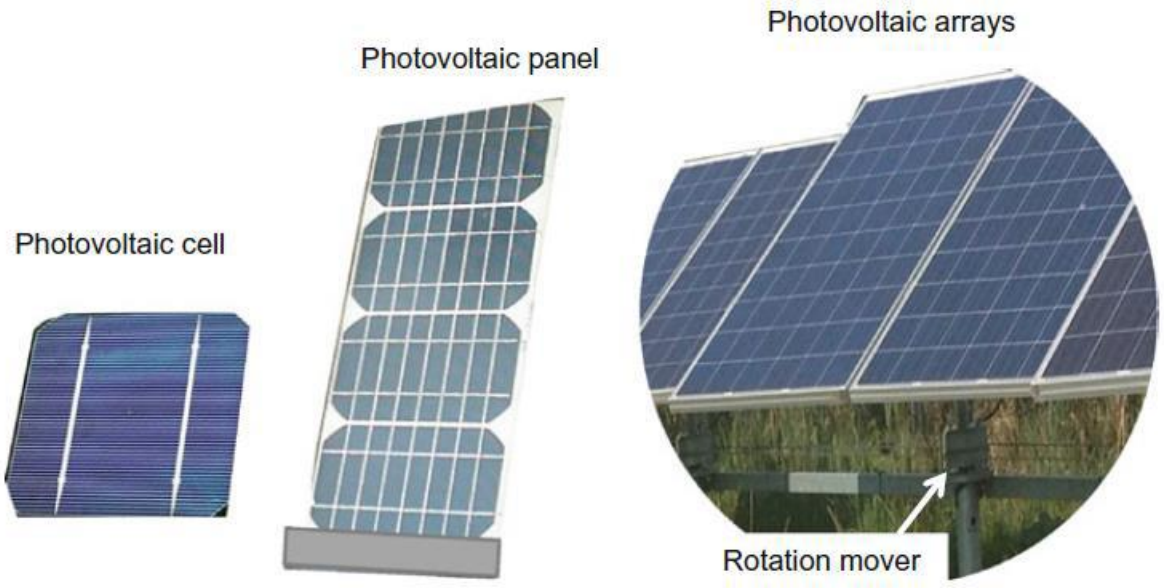


*Figure 8 :* From the PV cell to a PV power plant[21]

Total solar irradiance is the amount of radiant energy emitted by the sun over all wavelengths falling each second on a square meter perpendicular plane outside the earth's atmosphere. On the outer surface of the Earth's atmosphere the irradiance is known as the solar constant. The amount of solar energy that actually strikes a given area on the Earth is known as Insolation (incident solar radiation). Insolation varies with latitude, seasons and weather.[22]

### 2.3.2 Classification of Solar PV Plants

Solar PV plants can be classified as:

- Stand-alone PV systems for applications such as individual homes and water pumping.

Solar PV mini grids for a small community like a village.

- Grid-connected Solar PV plants for large scale grid integration.

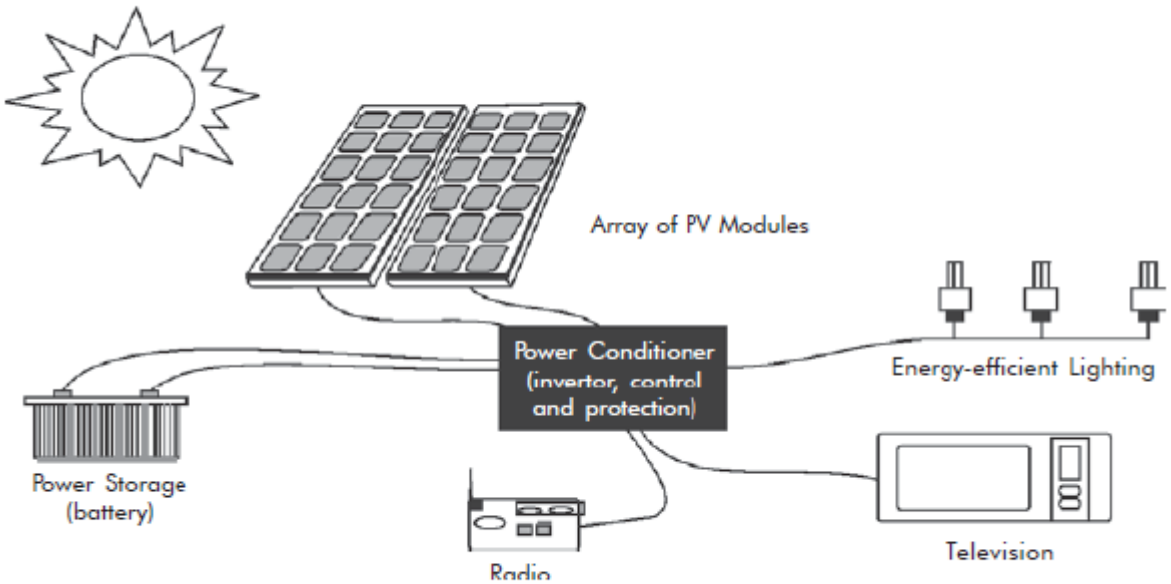


*Figure 9 :* Stand-alone solar PV System [23]

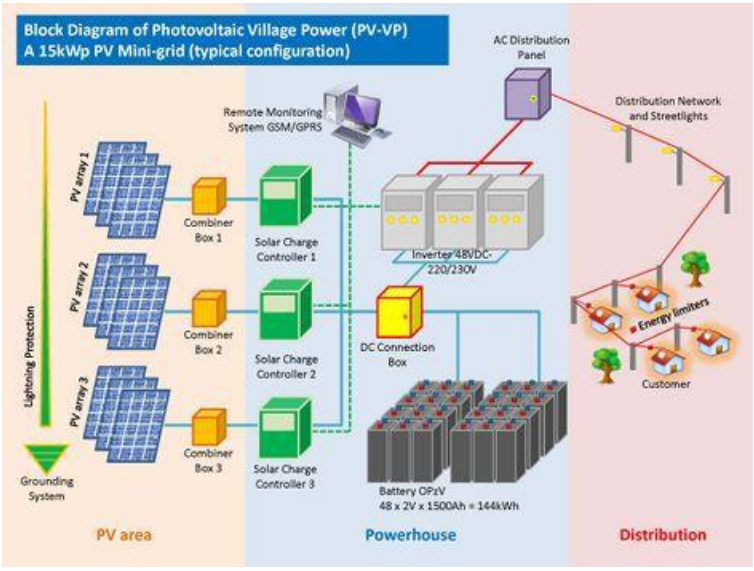


*Figure 10 :* Solar PV mini grid [24]

## 2.4 Advantages and disadvantages of solar energy

### 2.4.1 Advantages

- It is clean; it produces no emissions.
- It is renewable; the natural resource does not deplete.
- It is easily scalable; can be implemented in a wide range of sizes depending on need.
- It is quiet; there are no moving parts.
- It is reliable and requires very little maintenance.

### 2.4.2 Disadvantages

- It is expensive due to the difficulty in manufacturing solar cells.
- Low conversion efficiency of between 10 % and 20 %.
- It is intermittent; only available when there is sunshine.
- For continuous supply expensive storage is needed.
- Panels are fragile and can be damaged easily.
- Disposal requires care due to chemicals like arsenic and cadmium used in the production process.

## 2.5 Application of Solar photovoltaic system

- This is a system could be used for lighting purposes or for pumping water for a community or for irrigation.
- It can also work by converting sunlight into electrical power: It is achieved by using a thin layer of semi-conducting material, normally silicon, concealed in a plastic casing or glass. It is one of the cleanest forms of energy as it doesn't release emissions to the environment and its source is inexhaustible. [25]
- The semi-conducting material causes electrons in the materials' atoms to be knocked loose when the panels get exposed to sunlight. A direct current (DC) is then produced as the loosed electrons flow through the material. The direct current produced is then transferred via wires to an inverter, from which the current is converted to alternating current (AC) and then it is connected to the main electricity distribution board within the building. The electricity could either be used home or fed into the nations' grid system.[26]

## 2.6 Related Works

Asa T.Furman ,AND m.h Rshid discussed how solar energy can improve the economy. They showed how it will be improved in USA where it should exceed 6 gigawatt in 2010 and trying to analyze different technology which can contribute in the development of solar energy in the sectors of energy[11] .

Loránd Szabó discussed the history of using solar energy. They show how solar energy is not the new one but it has been used in the recent years[4].

There are many ways of improving the access of energy in different area. Eyram A. Adadevoh has Eyram A. Adadevoh discussed the method od shared solar energy where he said that solar energy has already proven itself to be a viable solution for meeting the electrification requirement of rural area which is now not only for rural area but also other area as connected area experiencing intermittent power supply[22] .

The technologies of solar energy are developing day to day. Many plants are developed in different country to maximize the use of solar energy as it is the best for climate change and for its abundance. A. Mengotti *et al.*, "Solar Thermal Power Plant," vol. 84, no. 14, 2014, in their work, they showed the working of solar thermal power plant and how it can be important in the electrification of a country[20]

# 3 Research Methodology

## 3.1 Introduction

The Methodology applied in this Dissertation is described inside this chapter. This chapter also presents strategy procedures utilized in this dissertation to get good results, revealing through discussion the primary method of collecting data. A description of adoption process and factors influencing adoption is additionally introduced inside this chapter. The limitations of the methodology, the sampling approach and method of interview design used to obtain data is also presented in this chapter

## 3.2 Research Strategy

This research is carried out in different districts. It focuses on a wide range of factors that affect the household's decision to adopt or non - adopt the solar energy system. There exist several literatures pertaining to the adoption, non adoption and barriers of solar energy system in terms of what the Government has executed or should do and in terms of what the population of viable adopters and non adopters needs the Government to do. However, few have integrated the opinion of the suppliers of these solar energy systems. The drives and barriers identified in the process have been used to explain why a number of households adopt solar energy and others don't. This has been answered to the determination of the factors that positively and negatively influence the adoption of solar energy in urban, peri-urban and rural areas.

## 3.3 Data collection method

To collect data different methods have been used. Three phases have been considered. Literature review was used to understand and have Information of solar energy and appliances. The identification of the site has been one of the steps to execute this work. Secondary data on solar energy systems (user and non-user households) have been collected from REG and related districts. This includes numbers of households in each district, solar energy users and non users. In Muhanga district with 319 141 population, where this research was conducted in Rongi sector ,which has 8001 households among them 613 are connected to the grid and 673 use solar panel systems .There the big number of solar Energy users are in Horezo village that uses only solar and count 116 households.

In Bugesera district with 361,914 populations, data was collected from Juru sector with 13,695 households among them 1914 Are on grid connected and 485 use solar energy where there is a Juru village that uses solar panels only and count 70 households.

In Kicukiro district with 318,564 population , this research was conducted in Kagarama ,where are located 14,385 households among them10,265households are connected to on grid and 4265 use both solar energy particularly solar water heater and electricity from the grid.

It was planned to collect Primary data using field visit methods for finding data to be used for determination of the proportion of working, deficient, and non working households' solar installations, but due to COVID 19 prevention measure, this method has not been done. Only Questionnaire by asking key informants, users and non-users and phone interview have been used to collect primary data.

The conducted interview to the key informants has played an important role in gaining data about specific factors of the adoption and non-adoption and helps to compare the adoption of solar energy in rural, peri urban and urban area.

The last and the main part of collecting data was the interview (personal interview and phone interview) done with households (adopters and non adopters) to determine the factors that positively and negatively influence the adoption and non adoption of solar energy and to get the factors that helped in comparing the adoption of solar energy between urban, peri urban and rural area.

## 3.4 Data Analysis

Collected data were analyzed using excel and pivot table for basic analyses. Moreover, the comparison of negative and positive factors that influence solar energy adoption as a function of habitat type was performed using the Logistic Regression Model in Rstudio software [27]

# 4 Results

During this research in the three identified habitat categories (urban, peri-urban, and rural), It was sampled and interviewed resident households as well as suppliers. The table below (Table 1) gives the total number of interviewed households and suppliers:

Table 1: Number of interviewees

| Habitat Category | Interviewees |
|---|---|
| Urban | 124 |
| Peri urban | 124 |
| Rural | 124 |
| Suppliers | 5 |
| Total | 377 |

The above numbers of interviewees is given in the following table according to their respective sector and cells

Table 2: Number of interviewees in each cell

| District | Sector | cells | Nr of interviewees |
|---|---|---|---|
| Urban /Kicukiro | Kagarama | Kanserege | 78 |
| | | Rukatsa | 46 |
| Peri urban / Bugesera | Juru | Juru | 70 |
| | | Mayange | 54 |
| Rural / Muhanga | Rongi | Horezo | 86 |
| | | Gisovu | 38 |

Among the interviewees there are solar energy adopters and non adopters (Tables 2 and 3). To use both categories helps to determine the positive factors for that influence the solar energy adoption and some negatives factors while using solar energy from adopters. On other hands it helped to determine negatives factors that influence non adopters to do not use solar energy and the barriers that they are facing to adopt solar energy.

Table 3: name of interviewed suppliers

| Nr | Names | Interviewee Position in the Company | Number of interviewed people in Company |
|---|---|---|---|
| 1 | DASSY Enterprise | Managing director | 1 |
| 2 | MUNYAXECO COMPANY | Chief technician | 1 |
| 3 | INNOTECH Ltd | Chief technician | 1 |
| 4 | BBoxx | Site engineer | 1 |
| 5 | Mobisol | Site engineer | 1 |

The perception of suppliers helped in comparing the solar energy adoption in rural peri urban and urban area.

## 4.1 Comparison of solar energy adoption in urban, peri- urban and rural areas

Table 4(see below) represents the total number of households in selected Sector Kagarama, Juru and Rongi respectively, and highlights the proportion of households that use solar energy. Both Table 4 and Figure 11 here below, using the official data from the Rwanda Energy Group show that the proportion of households using solar energy in our study area is higher in urban areas (15.7%) followed by the rural areas (8.4%) and the peri-urban areas (3.5%).

Table 4 : Number of households, users and non users in each habitat category [28]

| | **Urban/ Kagarama** | **Peri-urban/ Juru** | **Rural/ Rongi** |
|---|---|---|---|
| **Total households** | 14,385 | 13,695 | 8001 |
| **Users of Solar Energy** | 2,265 | 485 | 673 |

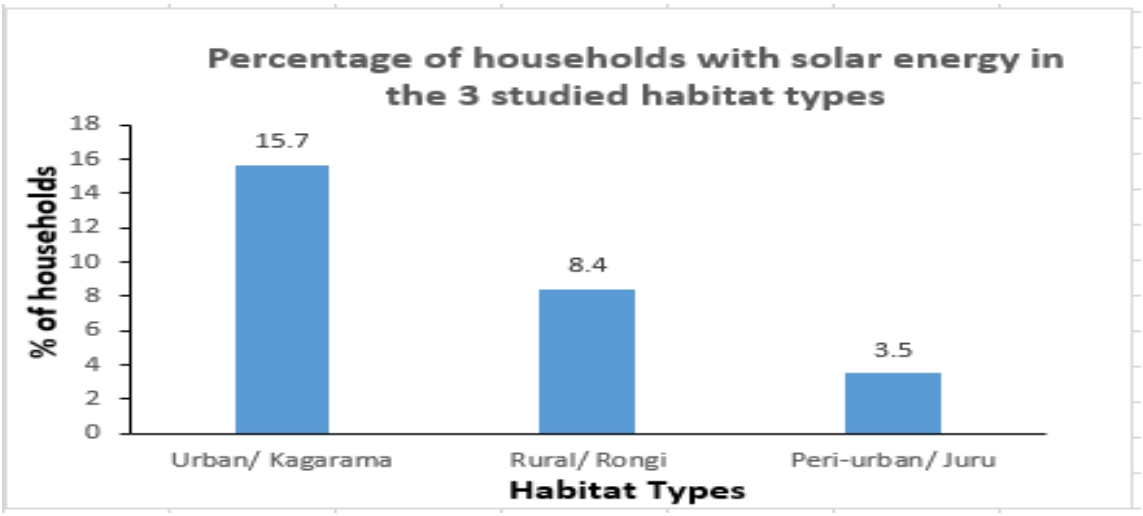


Figure 11 : ***Proportion (expressed as percentage) of households using solar energy in 3 studied habitat habitat categories***

### 4.1.1 Perceptions of solar energy systems' suppliers on solar energy adoption in urban, peri-urban and rural areas

The five interviewed suppliers were asked to give their opinion on what habitat category they think has the highest solar energy adoption and they ranked them in a descending order as: rural habitat (80% of respondents), urban (20% of respondents) and peri-urban (0% of respondents); as shown on the table and figure below:

Table 5: Perceptions of interviewed solar energy suppliers on solar energy adoption among habitat categories

| Name of company | Urban | Peri urban | Rural |
|---|---|---|---|
| DASSY Enterprise | 0 | 0 | 1 |
| MUNYAXECO COMPANY | 1 | 0 | 0 |
| INNOTECH Ltd | 0 | 0 | 1 |
| BBoxx | 0 | 0 | 1 |
| Mobisol | 0 | 0 | 1 |

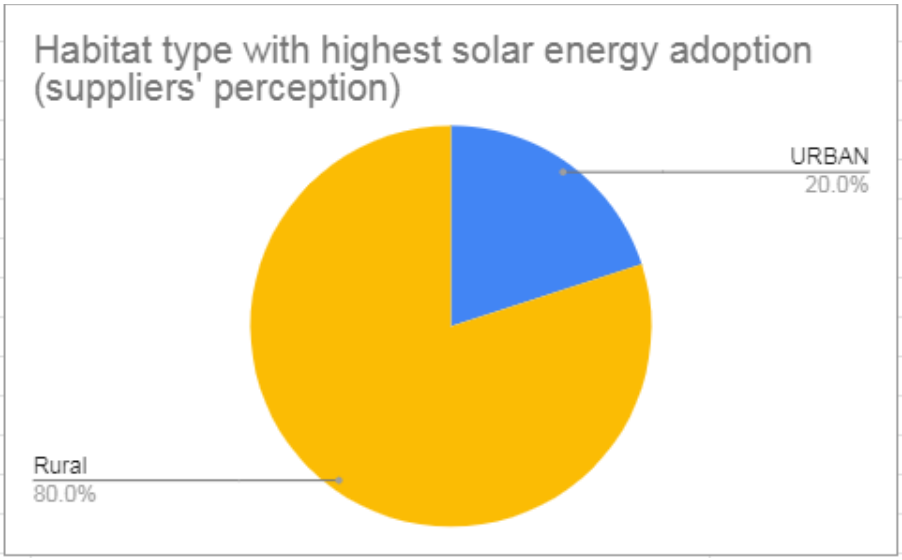


Figure 12 : ***Perceptions of interviewed solar energy suppliers on solar energy adoption among habitat categories***

## 4.2 Determination of factors that positively influence the adoption of solar energy in urban, peri-urban and rural areas.

The analysis of our data using the Logistic Regression Model (assigning the Poisson family of model) has shown that there is a variation (among the three habitat categories) of factors that positively affect the adoption of solar energy (Appendix 5). Particularly, there is a significant difference ($P = 0.01$) between the rural and urban habitat categories in the type and proportion of factors that positively influence solar energy adoption. However, the same analysis showed no significant difference ($P = 0.07$) between urban and peri-urban habitats as far as solar energy adoption positive factors are concerned.

### 4.2.1 Positive factors of solar energy adoption in Urban, Peri-urban and Rural habitats

The charts below show the perceptions of urban respondents on what motivated them to purchase a solar energy system and the advantages they experienced when they started using solar energy. In general, positive

factors that influence the adoption of solar energy are mainly the absence of permanent access to on-grid electricity, the willingness to use green energy and thus protect the environment, and the easy payment modalities. The main differences between rural and urban habitats is mainly that the top three positive factors for the rural areas are respectively the absence of permanent on-grid solar electricity, Easy payment modalities, and the willingness to protect the environment by using green energy; while for urban habitat, absence of permanent on-grid solar electricity, willingness to protect the environment by using green energy, and the fact of receiving a solar energy system as a donation. The easy payment modalities was highly considered in peri-urban and rural areas, while not even one urban respondent has mentioned it.

Table 5: ***Positive factors of solar energy adoption among the 3 different habitat categories***

| | Nr of responses | | |
|---|---|---|---|
| Positive factors | urban | Peri urban | Rural |
| Absence of permanent on grid electricity | 56 | 54 | 47 |
| Environmental protection (green energy) | 41 | 17 | 15 |
| Easy payment modalities (in installments) | 4 | 26 | 36 |
| Donation (by the Government or NGOs) | 12 | 17 | 16 |
| Energy bill payed for long term consumption | 5 | 7 | 5 |
| Compain (through REG OR EPD sector) | 6 | 3 | 5 |

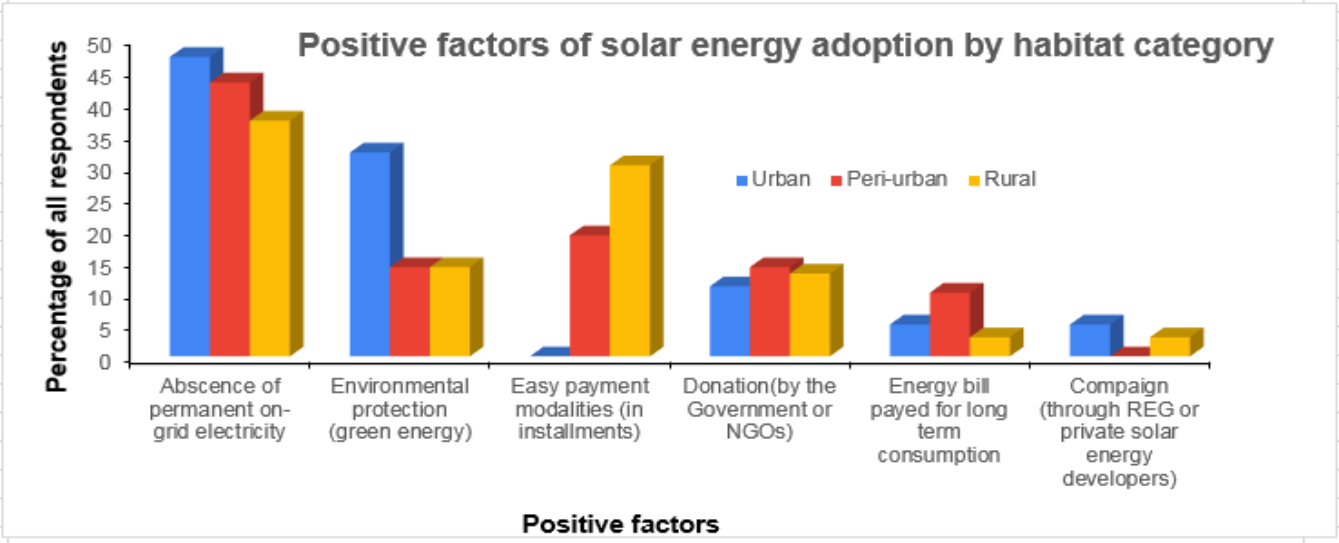


Figure 13: ***Positive factors of solar energy adoption among the 3 different habitat categories***

The positive factors of solar energy adoption are accompanied by a number of advantages that are classified by habitat category here below. The two main mentioned advantages are related to environmental protection, the long-term durability of the solar energy set, and little need for maintenance.

**Table 6 : Perceived advantages of using solar energy among different habitat categories**

| | Nr of response in each habitat category | | |
|---|---|---|---|
| Advantages | Urban | Peri urban | Rural |
| Less negative impact on the environment | 74 | 56 | 68 |
| Energy paid once for all (Long term) | 38 | 47 | 53 |
| Longer life with little maintenance | 12 | 21 | 3 |

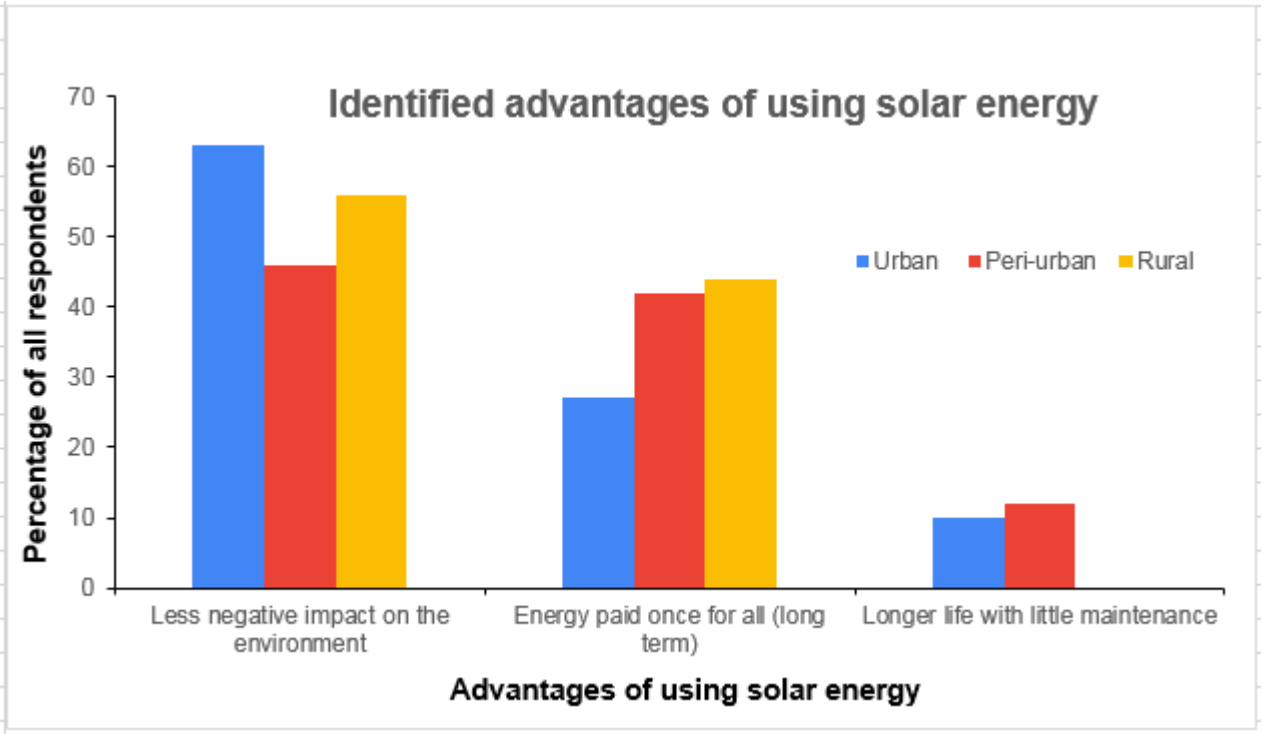


Figure 14: ***Perceived advantages of using solar energy among different habitat categories***

As shown on the figure 15 and table7 below, solar energy system suppliers have identified three main positive factors as the affordability (40%), Easy payment modalities (40%) and awareness and testimonies from existing users.

***Table 7:*** **Perceptions of solar energy suppliers on factors that positively affect solar energy adoption**

| | Nr of responses from relatives suppliers | | | | |
|---|---|---|---|---|---|
| Factors | DASSY Enterprise | MUNYAXECO COMPANY | INNOTECH Ltd | BBoxx | Mobisol |
| Affordability (Solar energy system is less expensive than on grid electricity) | 0 | 0 | 0 | 1 | 1 |
| Easy payment modalities | 0 | 0 | 1 | 0 | 0 |
| Awareness and testimonies from existing users | 1 | 1 | 0 | 0 | 0 |

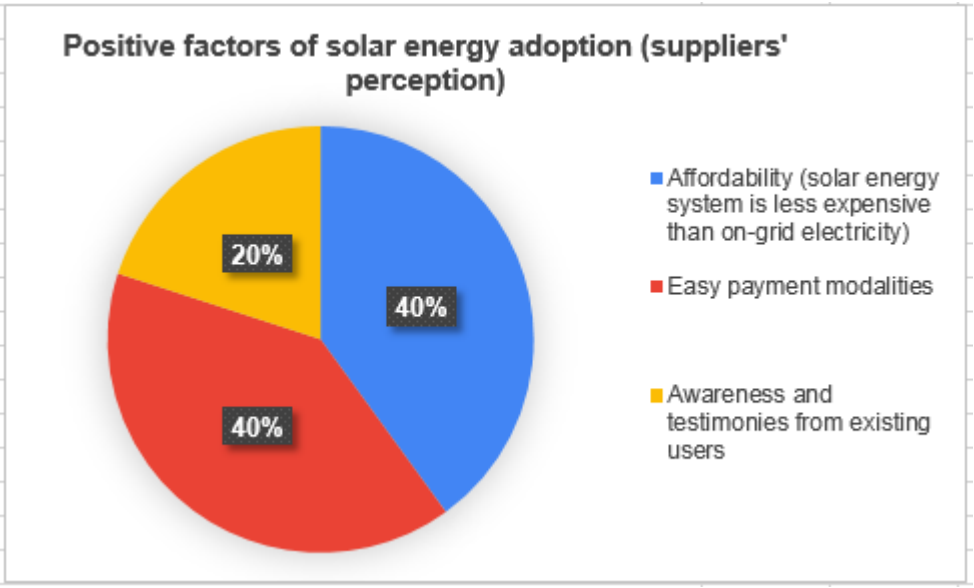


Figure 15: ***Perceptions of solar energy suppliers on factors that positively affect solar energy adoption***

## 4.3 Determination of factors that negatively influence the adoption of solar energy in urban, peri-urban and rural areas.

The analysis of our data using the Logistic Regression Model (assigning the Poisson family of model) has shown that there is no significant variation (among the three habitat categories) of factors that negatively affect the adoption of solar energy (Appendix 6). There is no significant difference ($P = 0.07$) between the rural and urban habitat categories in the type and proportion of factors that positively influence solar energy adoption. Moreover, the same analysis showed no significant difference ($P = 0.03$) between urban and peri-urban habitats as far as solar energy adoption positive factors are concerned.

### 4.3.1 Negative factors of solar energy adoption in Urban Peri-urban and rural habitats

The present study has also identified four main factors that negatively affect the adoption of solar energy in the habitats we surveyed. They include the expensive cost of the solar energy system, insufficiency of the solar energy system output mainly in urban and peri-urban areas, user-unfriendliness (because it may require frequent maintenance),and sufficient availability of on-grid electricity as urban peoples' first option. As the chart shows, it is very much harder to afford a solar energy system in the rural areas than in peri-urban and urban respectively.

Table 8: **Perception of Reason of not using solar energy system**

| | Nr of response in each habitat category | | |
|---|---|---|---|
| Factors | Urban | Peri urban | Rural |
| Affordability(too expensive ) | 42 | 57 | 86 |
| Insufficient output (Reason: Climate, high load, inappropriate installation ) | 52 | 58 | 27 |
| User unfriendliness (need of frequent maintenance, security) | 9 | 9 | 11 |
| National grid available as first option | 21 | 0 | 0 |

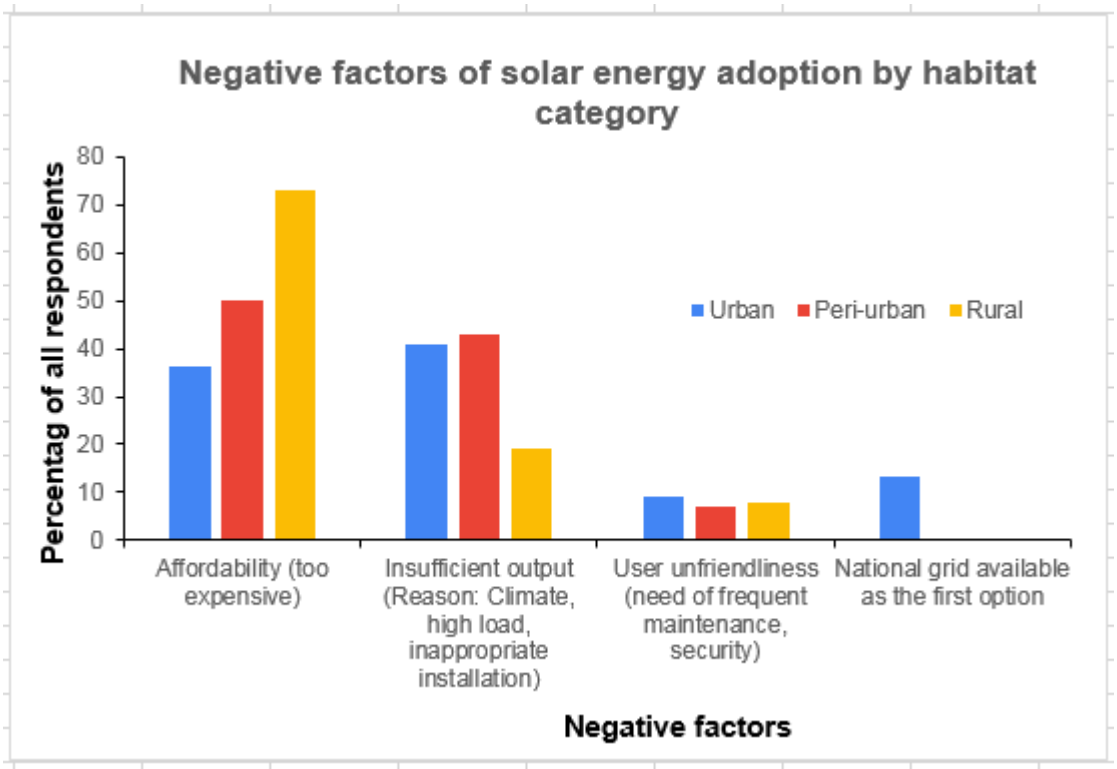


Figure 16: ***Perception of Reason of not using solar energy system***

In addition to the factors that negatively affect the adoption of solar energy systems, the present study has also identified eight disadvantages and common problems experienced by solar energy users. The figure below (Figure 17 and table 9) shows the 3 main issues that include: the intermittency of solar power (only

available where there is sunshine), fewer hours of electricity per day, and a weak power capacity than needed. As can be seen on the chart, solar system kits are much likely to be stolen in rural and peri-urban areas, while the security was not mentioned as an issue in the urban habitat. Moreover, the need for regular maintenance and the need for expensive storage in order to have continuous supply are issues that were reported only by respondents from peri-urban and rural areas.

Table 9: **Perception on disadvantages and common problems of solar energy systems in the three studied habitat categories**

| | Nr of responses | | |
|---|---|---|---|
| Disadvantages | Urban | Peri urban | Rural |
| It is intermittent( only available when there is sunshine) | 40 | 26 | 26 |
| Few hours of electricity than needed | 29 | 19 | 23 |
| Power less than needed | 28 | 26 | 12 |
| Security (likely to be stolen) | 0 | 16 | 21 |
| Panels are fragile and can be damaged easily | 15 | 7 | 13 |
| Need of regular maintenance | 2 | 9 | 11 |
| For continuous supply, expensive storage is needed | 2 | 11 | 7 |
| Others (payment, modalities, cost) | 8 | 10 | 11 |

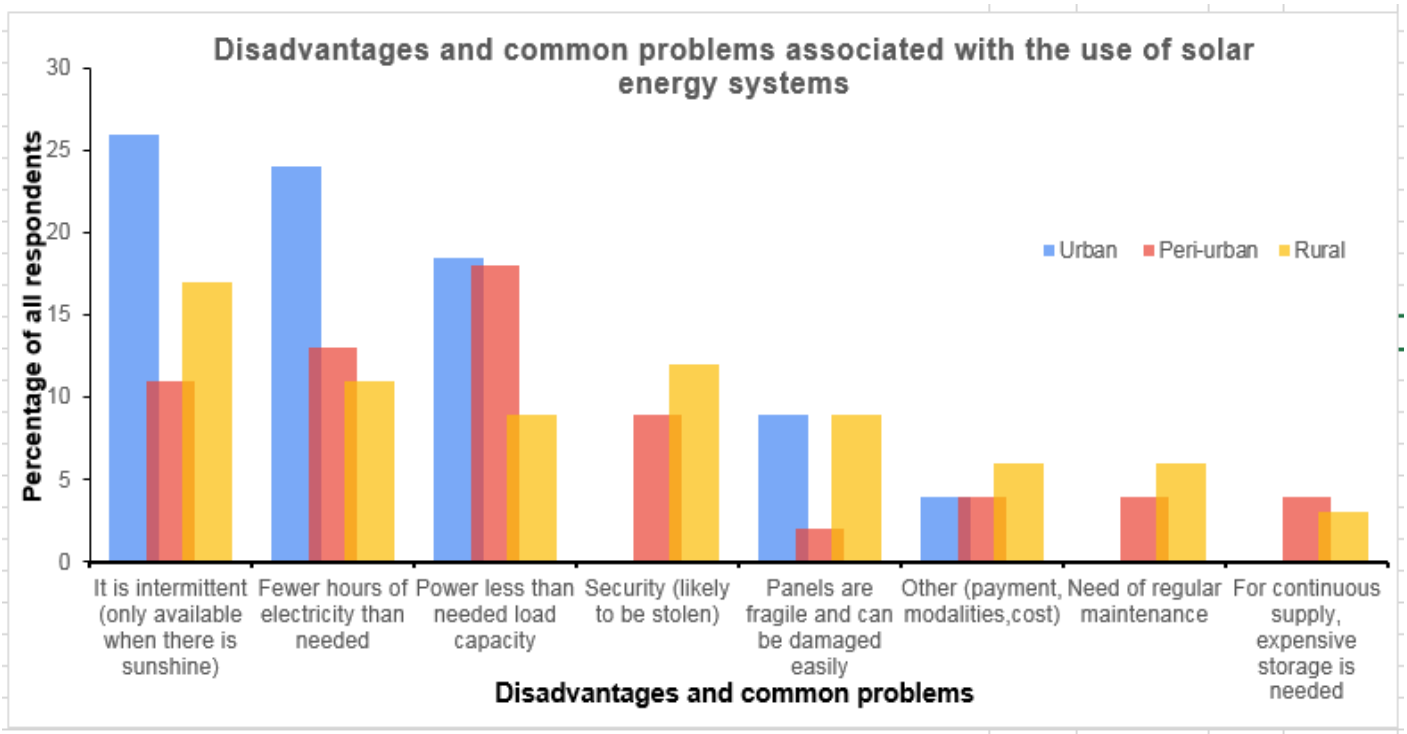


Figure 17: ***Perception on disadvantages and common problems of solar energy systems in the three studied habitat categories***

In the view of the interviewed solar system suppliers, three factors that negatively influence the adoption of solar energy are: the high cost (50%), inefficiency of the solar energy system (25%), and unsuitable weather (25%). As can also be seen on Figure 19, the high cost of the solar energy system is detrimental to the adoption of solar energy adoption, particularly in the rural and peri-urban areas.

Table 10: **Perceptions of solar energy suppliers on factors that negatively affect solar energy adoption**

| | Nr of responses from relatives suppliers | | | | |
|---|---|---|---|---|---|
| Factors | DASSY Enterprise | MUNYAXECO COMPANY | INNOTECH Ltd | BBoxx | Mobisol |
| Affordability (Solar energy system price is expensive for some people) | 0 | 1 | 0 | 1 | 1 |
| Solar energy system output is less than most users need | 1 | 0 | 0 | 0 | 0 |
| Weather that is not always sunny | 0 | 0 | 1 | 0 | 0 |

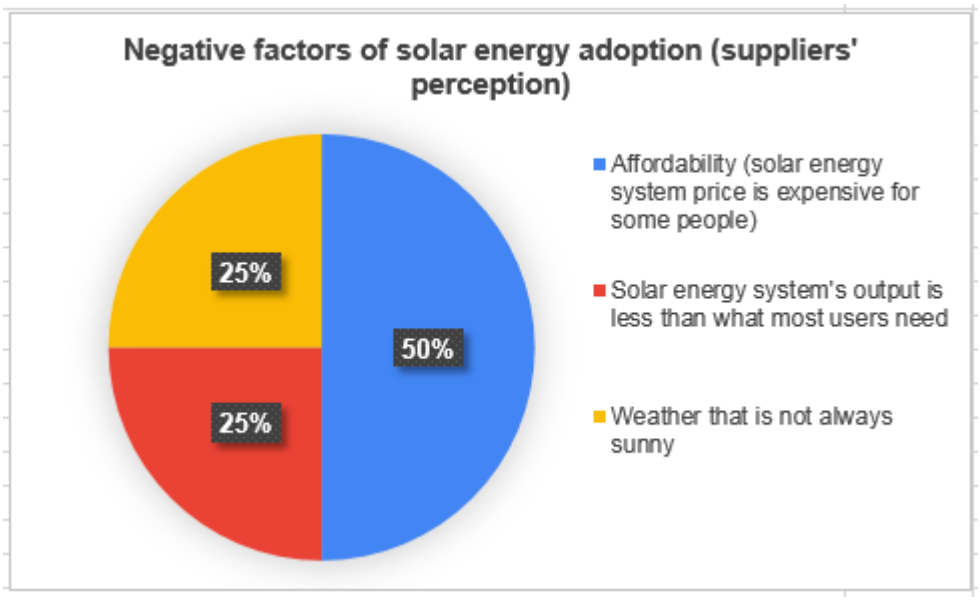


Figure 18 : ***Perceptions of solar energy suppliers on factors that negatively affect solar energy adoption***

## 4.4 Recommendations for the improvement of solar energy systems

From the tables (6,7,8,9 and 10), the improvement of solar energy systems mainly should emphasize on the need for improving storage capacity, reducing the cost, improving internal and external security, improving efficiency especially in urban habitat. The summary of recommendation on improvement of solar energy system is illustrated in figure 19

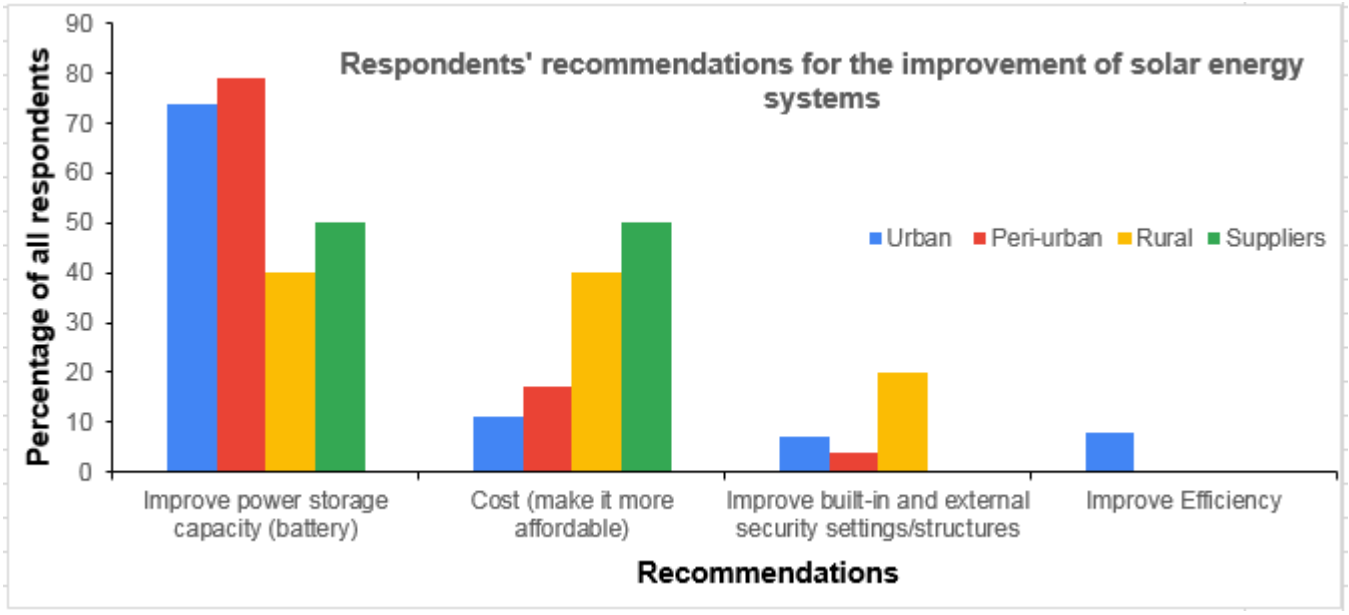


Figure 19: **Recommendations for the improvement of solar energy systems**

## 4.5 Discussions

In this party, the findings of this dissertation are discussed and focused on the comparison of solar energy adoption in rural, peri urban and urban areas and factors that influence positively and negatively the adoption of solar energy.

The data collected from the Rwanda Energy Group (REG) show that there is higher proportion of users in urban areas followed by the rural areas and the peri-urban areas, while according to the interviewed solar energy system suppliers; the rural habitat have the highest solar energy adoption. This difference between the perception of suppliers and the real data from REG can be explained by the fact that in urban area they don't only rely on PV system but also most of them use solar water heater.

The significant difference between urban and rural areas concerning the identified solar energy adoption positive factors, is due to the difference in the lifestyle and standards of living between those two habitats: having not mentioned 'easy payment modalities' among positive factors of solar energy adoption in urban area while it is one of the main factors for the rural solar energy systems indicate that urban households can afford buying a solar energy system more easily than rural households.

Moreover, even though the four main factors that negatively affect the adoption of solar energy were not significantly different in general, they demonstrate that it is very much harder to afford a solar energy system in the rural areas than in peri-urban and urban habitats respectively. They also show that solar energy system output is much likely to be more insufficient in urban and peri-urban habitats than in the rural areas. This fact can also be interpreted as a result of the difference in people's lifestyles in the countryside compared to life in the cities where the load is much likely to be bigger than the system's capacity.

The high cost of the solar energy system was proved to be detrimental to the adoption of solar energy adoption, particularly in the rural and peri-urban areas. At the same time, treating solar energy system inefficiency as well as improving the storage capacity particularly in urban and peri-urban areas is key to improving the adoption in those habitat types.

According to study done by M,G; Jimoh,A A [26] after alternative electricity solutions and effective with possible reduction; solar energy combined with smart grid can be the solution to the regular power supply from solar energy and its adoption in Namibia.

Furthermore, another research done on the adoption of solar energy [27] "need of having more regular power supply" has been identified as the dominant factor that influences residential to adopt solar energy.

The fact that solar energy is green and is good for the environment has been identified as dominant factor not only by interviewees but also most of the research done like [29] this has been mentioned as the best factor to encourage people to use solar energy system. Even if the bill payed for long is one of the positive factors but also the affordability are still the dominant negatives factors that influence the non adoption of solar energy. At the starting the solar energy cost is high, this is not only for Rwanda but also it has been mentioned by other researchers like Lewis, Nathan s [30] Discussing about the solar energy use they mentioned it as barrier to the adoption of solar energy.

# 5 Conclusion and recommendation

Given the ambition of the Rwandan government of achieving 100% access to electricity to all households in Rwanda by 2024 through the National Strategy for transformation (NST1), and the role that solar energy is expected to play in achievement of this ambition, our study of understanding the negative and positive factors of solar energy adoption in different habitat types was timely and necessary. Based on the findings from this study, the following recommendations were formulated for the improvement and acceleration of the solar energy adoption:

- After finding that the solar energy output is less than needed and most of people prefer to use on grid to meet their load capacity, Improve the solar system storage capacity mainly starting in urban and peri-urban areas as they need more electricity because of many action and have high load could lead to the high number of solar energy adoption.
- Affording solar energy particularly at the starting is the main negative factor that negatively influence the adoption of solar energy, therefore the Government should provide help and reduce cost by providing more facilitation to the suppliers or by donating or pay some part of cost for people to make it more affordable particularly starting from the rural habitat, and expanding to peri-urban and urban areas later.
- As mentioned by the most of all interviewees, the insufficient output of solar energy is a big problem and barrier to the adoption of solar energy particularly in urban area. Improving efficiency especially in urban habitat can lead to the solution of not relying only on grid but also use solar energy as first option.
- Most of interviewees in rural and peri urban mentioned the security problem, solar panels are likely to be stolen, therefore improvement of the internal and external security mechanisms / structures to avoid theft of the solar energy sets especially in the rural and peri-urban habitats is recommended to ensures the users the full security .
- Expand a similar study to the national level to capture the whole image on factors that drive the adoption and non-adoption of solar energy in Rwanda.

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# 7 Appendices

**Appendix 1: Questionnaire used for households (rural area, peri urban and urban area)**

**Question 1: What type(s) of source of electricity do you use?**

- ○ On-grid (proceed to question no. 2)
- ○ Solar Energy (Off-grid ) (proceed to question no. 3)
- ○ Both (On-grid and Off-grid) (proceed to question no. 3)
- ○ Other (Specify).....
- ◉ None (proceed to question no. 2)

**Question 2: Why don't you use off grid ( solar energy)?**

- ○ Affordability (too expensive)
- ○ Insufficient output (Reason: Climate, high load, inappropriate installation, other (specify).....)
- ○ User unfriendliness ( Reason: need of frequent maintenance, security , other(Specify).....)
- ○ Other.....

**Question 3: What were your motives for purchasing a solar energy system**

- ○ Abscence of on-grid electricity
- ○ It was given as a gift/ grant (by the RW government, NGO ...)
- ○ Easy payment modalities (in installments ...)
- ○ Energy bill payed for long term consumption
- ○ Environmental protection (green energy)
- ○ Compain by RW Gov (through REG or private solar energy developers,...)
- ○ Other.....

**Question 4**: **Do you plan to buy solar energy system in the future?**

- Yes
- No
- Maybe
- Suggestion if any: .....

**Question 5: When did you start using Solar energy system?**

**Question 6: What are the most frequent problems with your solar energy system?**

- Few hours of electricity than needed
- Need of regular maintenance
- Power less than needed load capacity
- Security (likely to be stolen)
- Other (payment, modalities,cost,...) .....

**Question 7: Do you have electricity every time you need it?**

- Yes
- No
- Sometimes
- Hours/day:.....

Question 8: **How satisfied are you with the performance of your solar system**

- satisfied
- Not Satisfied

**Question 9: What can be improved on the solar energy system?**

- Cost (make it more affordable)
- Improve power storage capacity (battery)
- Improve built-in and external security settings/structures
- Other.....

**Question 10: How do you compare using on-grid electricity and solar energy system**

- On-grid electricity is less suitable than solar energy system
- Solar energy is better than on grid electricity
- Solar energy is the same as on grid electricity
- On grid is much available compared to solar energy

**Question 11: Would you recommend others to use solar?**

- Yes
- No
- Maybe

Question 12: **What are the advantages of using solar?**

- Energy paid once for all (long term)
- Less negative impact on the environment
- Longer life with little maintenance
- It is renewable, the natural

**Question 13: What are the disadvantages of using solar?**

- It is expensive at the beginning
- It is intermittent (only available when there is sunshine)

- For continuous supply expensive storage is needed
- Panels are fragile and can be damaged easily
- Other.....

**Question 14: How does the weather condition impact the performance of your solar system?**

- Much
- A little bit
- Same all year round
- I don't know

Thank you so much. May God bless you!

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Appendix 2**: Questionnaire used for Suppliers**

**Question 1: Where do you think solar energy systems adoption is higher among these three habitats in Rwanda: 1.URBAN, 2.PERI-URBAN, 3. RURAL? (rank them as first, second and third)**

- First: .....
- Second: .....
- Third: .....

**Question 2: What factors do you think affect people's decision to adopt solar energy system?**

- Abscence of on-grid electricity
- Affordability (solar energy system is less expensive than on-grid electricity)
- Easy payment modalities (in installments ...)
- Energy bill payed for long term consumption
- Environment protection
- Other.....

**Question 3: What factors do you think affect people's decision not to adopt solar energy system?**

- Presence of on-grid electricity
- Most people cannot afford it (solar energy system is expensive)
- Payment modalities are not friendly
- Solar energy system's output is less than what most users need
- Solar energy systems are not durable (breakdown after a short time; need for frequent maintenance)
- Other.....

**Question 4: What impact do policies, laws and campaigns have on the adoption or non adoption of solar energy systems?**

- Very big

- Big
- Fair
- None
- I don't know

**Question 5: What were your motives for supplying solar energy system? (Choose all possible options)**

- Abscence of on-grid electricity
- Short time to design, install and start up a new plant
- Power out put matches very well with peak-loads demand
- It is highly modular (the plant economy is not strongly dependent on size)
- It is clean ,it produces no emissions
- It is renewable , the natural resources that do not deplete
- Other.....

**Question 6: In your opinion, how much are the users satisfied with the performance of their solar system?**

- Satisfied
- Not satisfied
- I don't know

**Question 7: What are the most frequent problems with the solar energy systems in your area of operation?**

- Few hours of electricity than needed
- Need of regular maintenance
- Power less than needed load capacity
- Security (likely to be stolen)

- Other (payment modalities, cost,...): .....

**Question 8: What do you suggest to be improved on the solar energy system?**

- Cost (make it more affordable)
- Improve power storage capacity (battery)
- Improve built-in and external security settings/structures
- other: .....

**Question 9: Personally, how do you compare using on-grid electricity and solar energy system ?**

- Much better
- Better
- Same
- I don't know

**Question 10: How does the weather condition impact the performance of your solar system?**

- Much
- A little bit
- Same all the year round
- I don't know

Thank you so much. May God bless you!

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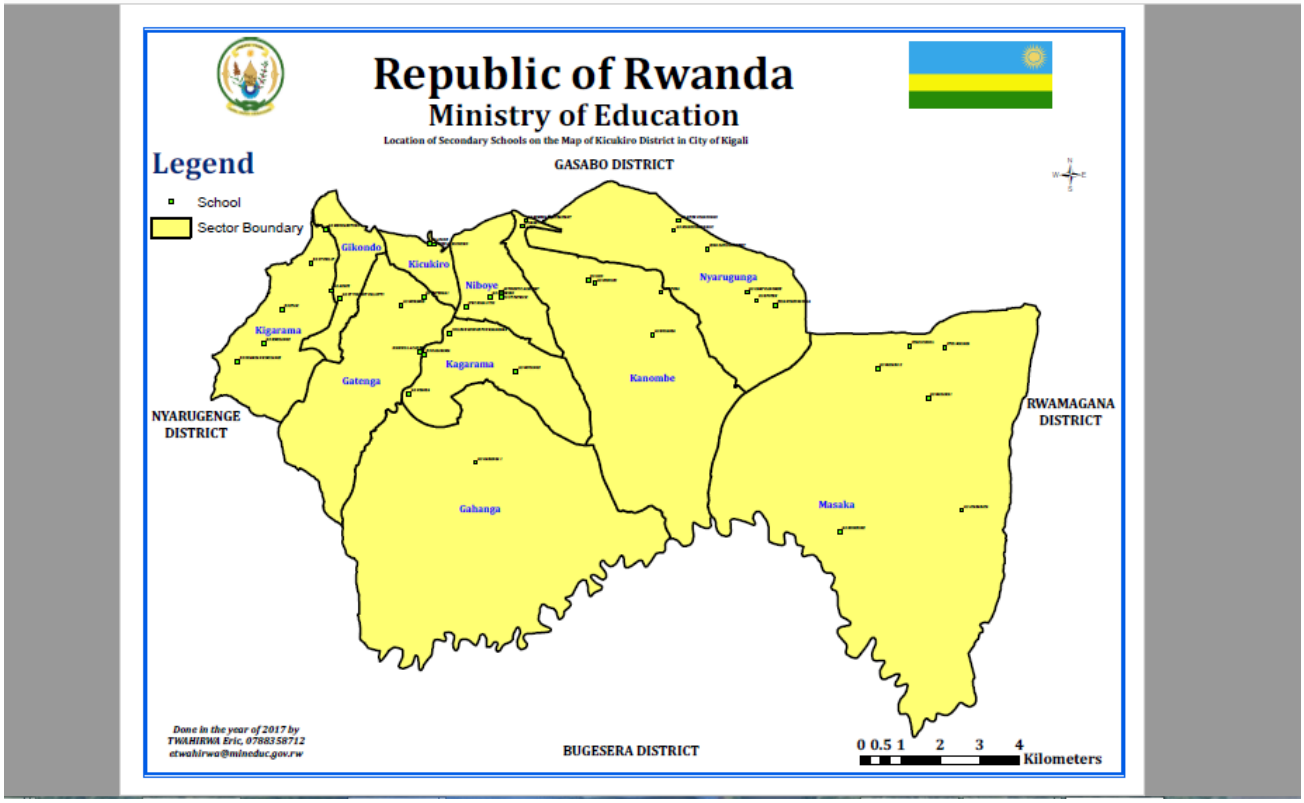
## Appendix 3: Geographical location of kicukiro district



Appendix 4 : Geographical location of Bugesera district

## Appendix 5: Data matrix imported into Rstudio for the of relationship between factors that positively influence the adoption of solar energy and the three studied habitat categories (urban, peri-urban and rural areas)

| ID | PositiveMotiv | HabitatCat |
|---|---|---|
| 1001 | 1 | 1 |
| 1002 | 1 | 1 |
| 1003 | 1 | 1 |
| 1004 | 1 | 1 |
| 1005 | 1 | 1 |
| 1006 | 1 | 1 |
| 1007 | 1 | 1 |
| 1008 | 1 | 1 |
| 1009 | 1 | 1 |
| 1010 | 1 | 2 |
| 1011 | 1 | 2 |
| 1012 | 1 | 2 |
| 1013 | 1 | 2 |
| 1014 | 1 | 2 |
| 1015 | 1 | 2 |
| 1016 | 1 | 2 |
| 1017 | 1 | 2 |
| 1018 | 1 | 2 |
| 1019 | 1 | 3 |
| 1020 | 1 | 3 |
| 1021 | 1 | 3 |
| 1022 | 1 | 3 |
| 1023 | 1 | 3 |
| 1024 | 1 | 3 |
| 1025 | 1 | 3 |
| 1026 | 1 | 3 |
| 1027 | 1 | 3 |
| 1028 | 1 | 3 |
| 1029 | 1 | 3 |
| 1030 | 2 | 1 |
| 1031 | 2 | 1 |
| 1032 | 2 | 1 |
| 1033 | 2 | 1 |
| 1034 | 2 | 1 |
| 1035 | 2 | 1 |
| 1036 | 2 | 2 |
| 1037 | 2 | 2 |
| 1038 | 2 | 2 |
| 1039 | 2 | 3 |
| 1040 | 2 | 3 |
| 1041 | 2 | 3 |
| 1042 | 2 | 3 |
| 1043 | 3 | 1 |
| 1044 | 3 | 1 |
| 1045 | 3 | 2 |
| 1046 | 3 | 2 |
| 1047 | 3 | 2 |
| 1048 | 3 | 3 |
| 1049 | 3 | 3 |
| 1050 | 3 | 3 |
| 1051 | 3 | 3 |
| 1052 | 4 | 1 |
| 1053 | 4 | 3 |
| 1054 | 5 | 1 |
| 1055 | 5 | 2 |
| 1056 | 5 | 2 |
| 1057 | 5 | 3 |
| 1058 | 6 | 2 |
| 1059 | 6 | 2 |
| 1060 | 6 | 2 |
| 1061 | 6 | 2 |
| 1062 | 6 | 3 |
| 1063 | 6 | 3 |
| 1064 | 6 | 3 |
| 1065 | 6 | 3 |
| 1066 | 6 | 3 |
| 1067 | 6 | 3 |
| 1068 | 6 | 3 |
| 1069 | 6 | 3 |
| 1070 | 6 | 3 |

**Key**

**1) Titles: ID:** respondent/ interviewee identification number; **PositiveMotiv =** positive factor; **HabitatCat** = Habitat category

**2) Values**: - **Positive factors** (Abscence of permanent on-grid electricity **= 1;** Environmental protection /green energy **= 2;** It was given as a gift/ grant /by the RW government, NGO **= 3;** Campaign/through REG or private solar energy developers **= 4;** Energy bill payed for long term consumption **= 5;** Easy payment modalities /in installments **=6**)

**- Habitat categories** (Urban = **1**; Peri-urban = **2**; Rural = **3**)

**Appendix 6: Data analysis result table: comparison of factors that positively influence the adoption of <u>solar energy in urban, peri-urban and rural areas</u>**

Call: glm(posFac$PositiveMotiv~as.factor(posFac$HabitatCat), family = "poisson")

**Deviance Residuals:**

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.408 | -1.2215 | -0.4824 | 0.912 | 1.869 |

**Coefficients:**

| | | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|---|
| (Intercept) *** | 0.000126 | 0.6391 | 0.1667 | 3.834 | 0.000126 *** |
| as.factor(posFac$HabitatCat)2 | | 0.3768 | 0.2122 | 1.776 | 0.075722 . |
| as.factor(posFac$HabitatCat)3 | | 0.503 | 0.196 | 2.566 | 0.010276 * |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 89.973 on 69 degrees of freedom

Residual deviance: 82.867 on 67 degrees of freedom

AIC: 275.77

Number of Fisher Scoring iterations: 5

## Appendix 7: Data matrix imported into Rstudio for the of relationship between factors that negatively influence the adoption of solar energy and the three studied habitat categories (urban, peri-urban and rural areas)

| ID | NegativeMotiv | HabitatCat |
|---|---|---|
| 1001 | 1 | 1 |
| 1002 | 1 | 1 |
| 1003 | 1 | 1 |
| 1004 | 1 | 1 |
| 1005 | 1 | 1 |
| 1006 | 1 | 1 |
| 1007 | 1 | 1 |
| 1008 | 1 | 1 |
| 1009 | 1 | 1 |
| 1010 | 1 | 2 |
| 1011 | 1 | 2 |
| 1012 | 1 | 2 |
| 1013 | 1 | 2 |
| 1014 | 1 | 2 |
| 1015 | 1 | 2 |
| 1016 | 1 | 2 |
| 1017 | 1 | 3 |
| 1018 | 1 | 3 |
| 1019 | 1 | 3 |
| 1020 | 1 | 3 |
| 1021 | 1 | 3 |
| 1022 | 2 | 1 |
| 1023 | 2 | 1 |
| 1024 | 2 | 1 |
| 1025 | 2 | 1 |
| 1026 | 2 | 1 |
| 1027 | 2 | 1 |
| 1028 | 2 | 1 |
| 1029 | 2 | 1 |
| 1030 | 2 | 2 |
| 1031 | 2 | 2 |
| 1032 | 2 | 2 |
| 1033 | 2 | 2 |
| 1034 | 2 | 2 |
| 1035 | 2 | 2 |
| 1036 | 2 | 3 |
| 1037 | 2 | 3 |
| 1038 | 2 | 3 |
| 1039 | 2 | 3 |
| 1040 | 2 | 3 |
| 1041 | 2 | 3 |
| 1042 | 2 | 3 |
| 1043 | 2 | 3 |
| 1044 | 2 | 3 |
| 1045 | 2 | 3 |
| 1046 | 2 | 3 |
| 1047 | 2 | 3 |
| 1048 | 2 | 3 |
| 1049 | 2 | 3 |
| 1050 | 2 | 3 |
| 1051 | 2 | 3 |
| 1052 | 2 | 3 |
| 1053 | 2 | 3 |
| 1054 | 2 | 3 |
| 1055 | 3 | 1 |
| 1056 | 3 | 1 |
| 1057 | 3 | 2 |
| 1058 | 3 | 3 |
| 1059 | 3 | 3 |
| 1060 | 4 | 1 |
| 1061 | 4 | 1 |
| 1062 | 4 | 1 |
| 1063 | 4 | 1 |

**Key**

**1) Titles: ID:** respondent/ interviewee identification number; **NegativeMotiv =** negative factor; **HabitatCat** = Habitat category

**2) Values**: - **Negative factors** (Affordability / too expensive **= 1;** Insufficient output **= 2;** User unfriendliness (need of frequent maintenance, security) **= 3;** National grid available as the first option **= 4**)

- **Habitat categories** (Urban = **1**; Peri-urban = **2**; Rural = **3**)

**Appendix 8: Data analysis result table: comparison of factors that negatively influence the adoption of <u>solar energy in urban, peri-urban and rural areas</u>**

**Call:** glm(formula = negFac$NegativeMotiv ~ as.factor(negFac$HabitatCat), family = "poisson")

**Deviance Residuals:**

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -0.81096 | -0.48876 | 0.08321 | 0.08321 | 1.20834 |

**Coefficients:**

| | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|
| (Intercept) 0.000126 *** | 0.71465 | 0.14586 | 4.899 | 9.61e-07 *** |
| as.factor(negFac$HabitatCat)2 | -0.2627 | 0.25832 | -1.017 | 0.309 |
| as.factor(negFac$HabitatCat)3 | -0.0809 | 0.20417 | -0.396 | 0.692 |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 20.713 on 62 degrees of freedom

Residual deviance: 19.646 on 60 degrees of freedom

AIC: 181.92

Number of Fisher Scoring iterations: 4

Appendix 9: **Answered questionnaire for households**

**ASSESMENT OF SOLAR ENERGY ADOBPTION AND NON-ADOPTION IN RURAL AREA**

**District: Muhanga**

**Sector: Rongi**

**Gender: Male**

**Question 1: What type(s) of source of electricity do you use?**

- ○ On-grid (proceed to question no. 2)
- ◉ Solar Energy (Off-grid ) (proceed to question no. 3)
- ○ Both (On-grid and Off-grid) (proceed to question no. 3)
- ○ Other (Specify).....
- ○ None (proceed to question no. 2)

**Question 2: Why don't you use off grid ( solar energy)?**

- ○ Affordability (too expensive)
- ○ Insufficient output (Reason: Climate, high load, inappropriate installation, other (specify).....)
- ○ User unfriendliness ( Reason: need of frequent maintenance, security , other(Specify).....)
- ○ Other.....

**Question 3: What were your motives for purchasing a solar energy system**

- ◉ Abscence of on-grid electricity
- ○ It was given as a gift/ grant (by the RW government, NGO ...)
- ○ Easy payment modalities (in installments ...)
- ○ Energy bill payed for long term consumption
- ○ Environmental protection (green energy)
- ○ Compain by RW Gov (through REG or private solar energy developers,...)
- ○ Other.....

**Question 4: Do you plan to buy solar energy system in the future?**

- ○ Yes
- ○ No
- ◉ Maybe

- Suggestion if any: .....

**Question 5: When did you start using Solar energy system?**

2018

**Question 6: What are the most frequent problems with your solar energy system?**

- Few hours of electricity than needed
- Need of regular maintenance
- Power less than needed load capacity
- Security (likely to be stolen)
- Other (payment, modalities,cost,...) .....

**Question 7: Do you have electricity every time you need it?**

- Yes
- No
- Sometimes
- Hours/day:.....

Question 8: **How satisfied are you with the performance of your solar system**

- satisfied
- Not Satisfied

**Question 9: What can be improved on the solar energy system?**

- Cost (make it more affordable)
- Improve power storage capacity (battery)
- Improve built-in and external security settings/structures
- Other.....

**Question 10: How do you compare using on-grid electricity and solar energy system**

- On-grid electricity is less suitable than solar energy system
- Solar energy is better than on grid electricity
- Solar energy is the same as on grid electricity
- On grid is much available compared to solar energy

**Question 11: Would you recommend others to use solar?**

- Yes
- No

- [x] Maybe

Question 12: **What are the advantages of using solar?**

- [ ] Energy paid once for all (long term)
- [x] Less negative impact on the environment
- [ ] Longer life with little maintenance
- [ ] It is renewable, the natural

**Question 13: What are the disadvantages of using solar?**

- [ ] It is expensive at the beginning
- [ ] It is intermittent (only available when there is sunshine)
- [ ] For continuous supply expensive storage is needed
- [x] Panels are fragile and can be damaged easily
- [ ] Other.....

**Question 14: How does the weather condition impact the performance of your solar system?**

- [ ] Much
- [x] A little bit
- [ ] Same all year round
- [ ] I don't know

Thank you so much. May God bless you!

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Appendix 10: **Answered questionnaire for suppliers**

**ASSESMENT OF SOLAR ENERGY ADOBPTION AND NON-ADOPTION IN RURAL AREA**

**Name of Company:** DASSY Enterprise

**Question 1: Where do you think solar energy systems adoption is higher among these three habitats in Rwanda: 1.URBAN, 2.PERI-URBAN, 3. RURAL? (rank them as first, second and third)**

- First: .....
- Second: .....
- Third: .....

Question 2: **What factors do you think affect people's decision to adopt solar energy system?**

- Abscence of on-grid electricity
- Affordability (solar energy system is less expensive than on-grid electricity)
- Easy payment modalities (in installments ...)
- Energy bill payed for long term consumption
- Environment protection
- Other..... Lack of awareness and similar best cases from existing users.....

**Question 3: What factors do you think affect people's decision not to adopt solar energy system?**

- Presence of on-grid electricity
- Most people cannot afford it (solar energy system is expensive)
- Payment modalities are not friendly
- Solar energy system's output is less than what most users need
- Solar energy systems are not durable (breakdown after a short time; need for frequent maintenance)
- Other.....

**Question 4: What impact do policies, laws and campaigns have on the adoption or non adoption of solar energy systems?**

- Very big
- Big
- Fair
- None
- I don't know

**Question 5: What were your motives for supplying solar energy system? (Choose all possible options)**

- Abscence of on-grid electricity
- Short time to design, install and start up a new plant
- Power out put matches very well with peak-loads demand
- It is highly modular (the plant economy is not strongly dependent on size)
- It is clean ,it produces no emissions
- It is renewable , the natural resources that do not deplete
- Other.....

**Question 6: In your opinion, how much are the users satisfied with the performance of their solar system?**

- Satisfied
- Not satisfied
- I don't know

**Question 7: What are the most frequent problems with the solar energy systems in your area of operation?**

- Few hours of electricity than needed
- Need of regular maintenance
- Power less than needed load capacity
- Security (likely to be stolen)
- Other (payment modalities, cost,...): .....

**Question 8: What do you suggest to be improved on the solar energy system?**

- (•) Cost (make it more affordable)
- ( ) Improve power storage capacity (battery)
- ( ) Improve built-in and external security settings/structures
- ( ) other: .....

**Question 9: Personally, how do you compare using on-grid electricity and solar energy system ?**

- ( ) Much better
- ( ) Better
- (•) Same
- ( ) I don't know

**Question 10: How does the weather condition impact the performance of your solar system?**

- ( ) Much
- (•) A little bit
- ( ) Same all the year round
- ( ) I don't know

Thank you so much. May God bless you!

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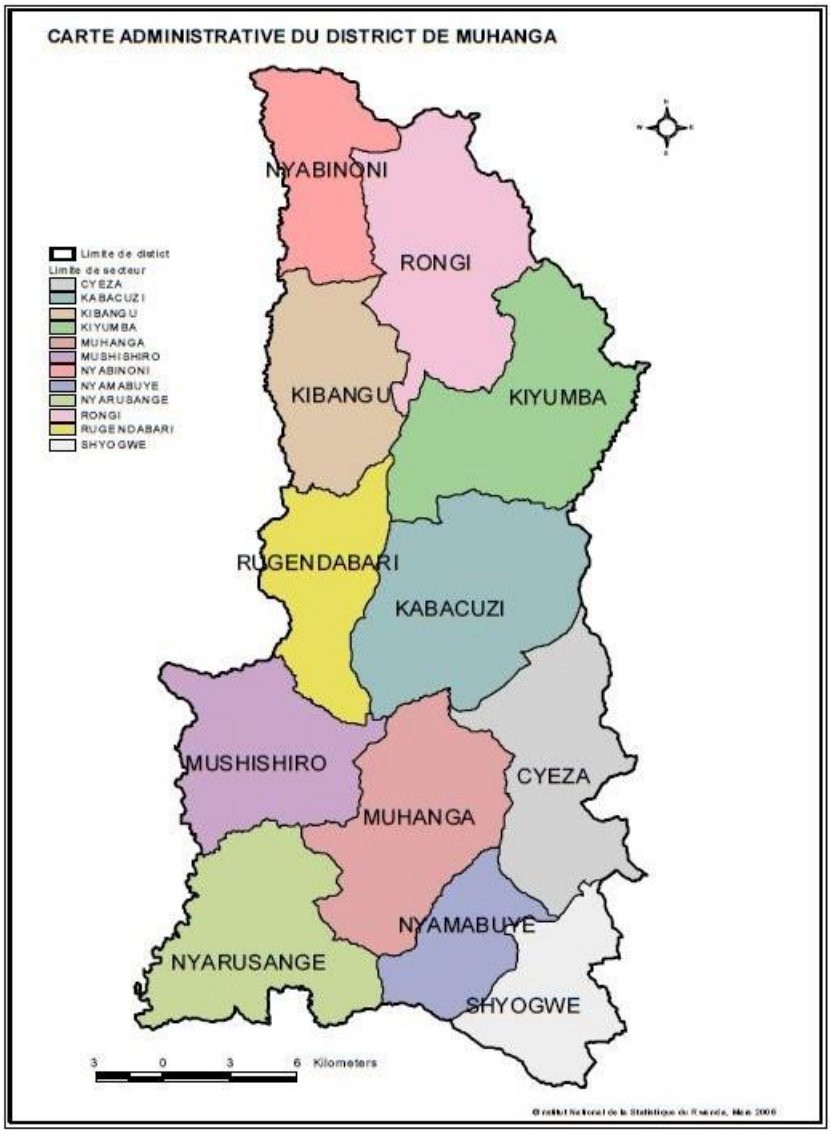
## Appendix 11: Geographical location of Muhanga district


CARTE ADMINISTRATIVE DU DISTRICT DE MUHANGA
Limite de district
Limite de secteur
CYEZA
KABACUZI
KIBANGU
KIYUMBA
MUHANGA
MUSHISHIRO
NYABINONI
NYAMABUYE
NYARUSANGE
RONGI
RUGENDABARI
SHYOGWE
NYABINONI
RONGI
KIBANGU
KIYUMBA
RUGENDABARI
KABACUZI
MUSHISHIRO
CYEZA
MUHANGA
NYAMABUYE
NYARUSANGE
SHYOGWE
3 0 3 6 Kilometers