ASSESSMENT OF SOLAR HOME SYSTEMS AND SOLAR MINI GRIDS- A CASE FOR SINDA AND MPANTA VILLAGES IN ZAMBIA

BY

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Abstract

The purpose of the research was to assess the impact of the two types of solar photovoltaic technologies which are available in our rural communities in Zambia. This study presents the results of socio-technical assessment of solar photovoltaic interventions namely solar home systems (SHS) and solar mini-grid (SMG), which have been used to electrify Sinda villages and Mpanta Village. The study is focused on technical, financial, and institutional aspects along with the social impact assessment of PV based electrification. The results of the study show that the impacts of the solar PV systems used for electrification have been largely positive, especially in benefits of uplifting the living standards of these communities such as, increased refrigeration storage and ease in studying by school going children.

In undertaking the research, it was observed that the SMG and SHS in the considered villages basically operate on the same principle and the types of appliance that are allowed to be used on the systems are similar. However, the SMG is superior to the SHS in that it supplies power to a larger community whilst the SHS is operated at individual level. The beneficiaries of the SMG are residential clients, schools, rural health centers (RHS), harbor depots and churches within these communities. Another factor that makes SMG more beneficial is that clients with less resource are able to benefit since they are able to be connected to the grid for free or in some cases are asked to pay a small connection fee. This was the case in Mpanta were the Government of Zambia initially allowed clients to be connected for free to the SMG whilst their counterparts in Sinda village are asked to pay a connection fee of K100 (US $9.68). However, in Mpanta village, would-be clients at present are asked to pay a connection fee of K40 (US $3.87).

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Contents

List of Figures

List of Table

Abbreviations

CFL	Compact Fluorescent Lamp
DC	Direct Current
DoD	Depth of Discharge
DOE	Department of Energy
ERB	Energy Regulation Board
ESCO	Energy Service Company
ESMAP	Energy Sector Management Assistance Program
IRENA	International Renewable Energy Agency
KCS	Kafita Cooperative Society
LCOE	Levelised Cost of Energy
LED	Light Emitting Diode
MPPT	Maximum Power Point Tracker
NGO	Non-Governmental Organization
PV	Photovoltaic
REA	Rural Electrification Authority
SHS	Solar Home System
SMG	Solar Mini Grid
SPSS	Statistical Package for Social Science
VDC	Voltage direct current
Wp	Watt Peak
ZBS	Zambia Bureau of Standards
ZDA	Zambia Development Agency

Chapter 1: Background

1.0 Introduction

Zambia has an average solar insolation of 5.5 kWh/m2/day, with approximately 3,000 sunshine hours annually, providing a good potential for solar photovoltaic applications Singh et al, 2013. Despite this solar resource, solar energy technology penetration has remained relatively low due to high initial capital cost. As such the solar energy market in Zambia is dominated by donor funded projects, Government and NGOs (ZDA, 2014).

The main source of power generation in Zambia is from hydro power which accounts for 94% of the generated power while solar power falls within the remaining 6% of power produced from other sources. The national; access rate for electricity is 44% and only 3% of rural areas have access to power (ERB, 2015).

To date the Rural Electrification Authority (REA), Ministry of Energy and Water Development (MWED), energy service companies, NGOs, solar energy companies and individuals have installed solar photovoltaic (PV) systems in schools, rural health centers, chief's palaces and households.

The Government of the Republic of Zambia (GRZ) has also liberalized the energy sector to allow solar energy companies to set up solar mini grids to enable the supply of solar power to rural communities. Currently there are three solar mini-grid systems in operational in the country namely Mpanta with an installed capacity of 60kW, Lundazi Green Village Solar power with an installed capacity of 45kW and the Sinda Solar Mini-Grid Power with an installed capacity of 25kW. Two more solar mini grids are in the process of being developed, these being the Lunga Solar Mini Grid which will be a 300kW capacity and the Chunga Solar Mini Grid which will be a 200kW capacity. The Mpanta Solar Mini-Grid is owned by GRZ and is being managed by the Rural Electrification

Authority (REA) and the community, Lundazi Green Village is owned by GRZ and is being managed by the community, and Sinda Solar Mini-Grid is a privately owned and managed by Muhanya Solar.

The solar home systems and solar mini-grids are the two common technology option applied in solar rural electrification and they have been met with challenges which hamper smooth running of these installations.

The research critically examined the two technologies on how they are impacting the rural communities by looking at the affordability, sustainability, load management, socio-economical, cost of investment and operation and maintenance costs.

1.1 Statement of the problem

The GRZ with cooperating partners and NGOs has, from times to date embarked on electrification of rural areas in Zambia by installing of solar photovoltaic systems. Some systems had only operated for a number of years and had become non-operational after a few years of installation and in certain cases not operated at full capacity.

Therefore there was need to evaluate the solar home systems and solar mini grids, to examine the challenges which led to the non-operational of these systems and how these systems are impacting on rural community's livelihood.

1.2 The purpose of the study

The purpose of the research was to investigate the solar technologies workability in rural areas of Zambia and how the technology is bringing about development in these areas. Since the two technologies that are mostly used are solar home systems and solar mini grids, the assessment of these systems was investigated, typically on how individuals load systems, on the measures which management/individuals take to mitigate the problems and on sustainability of the projects or enterprises.

1.3 Research objectives

The main objective of the research was to assess the facilities of solar home systems and solar mini-grids in Zambia's rural areas. The specific objectives were;

- to discuss the income activities which can lead to sustainability and affordability of the technology in project areas
- to state the cost of investments, operation and maintenance of solar home systems and solar mini grid technologies in the study areas
- to review the regulatory and standards of solar home systems and solar mini grids
- to discuss the limitations and merits of solar home systems and solar mini grids.

1.4 Research Questions

The main research question is: how do the socio economic factors affect the operation of solar home systems and solar mini-grids in rural Zambia?

The specific research questions are as follows;

- What are the economic activities which can lead to the sustainability and affordability of the solar technology in the rural areas?
- What is the cost of investment and, operation and maintenance?
- How are the effective procedures of maintaining the systems?
- What are the regulatory and standards of these systems?
- What are the limitations and merits of the systems?

1.5 Scope of Study

The focus of the research was in the two project areas where the solar mini-grids have been installed, i.e. Mpanta in Samfya Luapula province and Sinda in Eastern province. These areas were chosen because they comprise of individuals owning solar home systems and those that are connected to the solar mini-grid.

1.6 Significance of Study

The study helps to determine the direction of investments for rural electrification and can ultimately inform government and public policy.

The research helped in determining the benefits of existing solar energy technologies in Zambia and also helped to determine how the dynamics of different economies of the rural areas affect the development of solar energy technologies.

1.7 Operational Definitions

Solar photovoltaic systems in rural Zambia involve off-grid solar systems which have a semi-autonomous capability to satisfy electricity demand through local power generation. The term “off-grid systems” covers both solar mini-grids (serving multiple customers) and solar home systems for individual users. Off-grid solar systems can be mini and micro grid, and do not depend on electricity provided through main grids power infrastructure.

- Solar home systems (SHS) can be defined as small solar photovoltaic systems consisting of one or more solar PV modules with a total peak power of between 80Wp to 500Wp with a battery, inverter and a charge controller. These are used for powering household appliances such as lights, radio, television and fans. The power output can either be alternating current (AC) or direct current (DC) systems.
- Solar mini-grids are generally used in clustered communities where a grid network is used to supply power to the community within a radius of about 2km. They consist of a power house where inverters of kilowatt capacities, charge controllers and batteries are situated. The power generated is usually distributed by a single phase system. It can be used for lighting, refrigeration, pumping of water for domestic use, irrigation and other electrical home appliance.

Chapter 2: Literature Review

2.0 Introduction

This chapter present the review of literature related to the study. It also comprises of the theoretical framework which guided this study to the state, status and initiative of the solar mini grids and solar home systems in rural Zambia.

2.1 Theoretical Framework

In research, theories are very important because they provide a way towards solving the research study being undertaken. The theoretical approach which was adopted in this study can be opted for future studies on standalone solar home systems and solar mini-grids in rural Zambia. This study was therefore guided by the Diffusion of Innovation theory (Rodgers, 2003), Domestication theory developed (Silverstone et al., 1994) and the Lazy User theory (Tetard and Collan, 2009).

2.1.1The Diffusion of Innovation Theory

Diffusion is the process by which an innovation is communicated through some channels over time among the members of a social system. This theory explains how and why innovations spread across cultures, organizations, society and communities. A few key constructs used are relative advantage, ease of use, visibility compatibility, results demonstrability and voluntariness of use. These are some of the key variables relevant to improving operation of solar systems in rural areas. The theory also helps to describes how individual are expected to undertake new innovations like solar mini-grids and solar home systems.

2.1.2 Domestication Theory

Domestication Theory essentially is about giving technology a place in everyday life. The concept catches the practical, temporal, spatial place, but most importantly, it underlines how this is mixed with the cultural as an expression of lifestyles and values.

Firstly technologies are integrated into everyday life and adapted to daily practices. Secondly, the user and its environment change and adapt accordingly.

The theory has expanded in the innovation literature as a tool to understand technologies and innovations entering any consuming unit such workplace, homes, country etc.as stated by (Lie et al, 1996) that it can be analyzed economically, culturally and sociologically. The domestication approach considers both the practical and the symbolic aspects of the adoption and use of technologies. These two elements show the meanings of things, and their materiality, are equally important understanding how technologies become part of everyday life. It is a social theory that highlights the challenges to power and control, the introduction of technologies into any social setting.

It drives the approach to understanding how technology is created, the role of users in innovation, the work done by individuals and communities in order to make a technology from the outside do practical work, and make sense within that community. The theory helped in this research to understand the technological aspect on how the solar mini-grid and solar home systems can be used for practical applications such as solar lighting and solar refrigeration in the rural areas.

2.1.3 Lazy User Theory

The lazy user theory of solution selection explains how an individual (user) makes her selection of solution to fulfill a need (user need) from a possible solution. The position that the lazy user theory of selection takes is that from the possible available solution a user selects the solution that demands least effort. This has implications on how and on how products and services should be designed and on how users adopt and attach them. In the context of solar systems in rural areas the designs should not be imposed to the communities (users) but they should be designed in such a way that they are able to solve their problems.

2.2 Relevant Literature Reviewed

Kenya has been a proven success of solar home system diffusion, despite the widespread diffusion of solar photovoltaic technologies, a lack of trained and qualified technician's at local levels is a challenge to solar home system product suppliers (Laura et al., 2012).

Studies on the operation of solar photovoltaic systems have been done around the world. In Cuba an evaluation of factors that determined the loss of operative's state of the system by periodic technical inspection were done. The data analyzed on the medium frequency of failures indicated problems of technology and its social adoption (Lopez et al., 2000).

Similarly in the designing of most rural based electrification projects, project designers have mostly considered lighting as the main need of rural people. In Mpanta village it was noticed that communities had been by passing load limiters, these act as circuit breakers to manage the amount of current that is drawn by the consumer as stated by (Mubanga, 2016). Therefore if households connected prohibited appliances such as cookers, welding machines, grinders and other high voltage equipment this becomes illegal connections. Also some cases where customers by passed load limiters to connect more load and disconnected customers reconnected themselves to the grid constituting illegal connections.

In 1996 the Department of Energy (DOE), Government of Zambia, began to discuss how small-scale solar technology could fit in the rural electrification policy of Zambia. These discussion led to a project called the Zambia PV-ESCO project that received funding from

Swedish International Development Cooperation Agency (Sida) in 1999. The aim of the project was to support the operation of three ESCOs in Eastern Province operating a total of 406 SHS as stated by (Gustavsson, 2006).

In a similar attempt to identify specific problems and difficulties experienced with solar photovoltaic systems and accessories installed in some Asian countries indicated that the problems were related to almost all aspects of the photovoltaic accessories as well as sizing of systems, institutional set-up and maintenance that influence electricity demand and consumption in solar home systems and hence the system design and performance (Kumar et al., 2000).

The system performance related aspects where also evaluated in twelve projects funded during 1993 to 2000 from the portfolio of the World Bank and Global Environment Facility (Eric et al., 2001), spread in many countries including Morocco, Lao PDR, India, Argentina and China. The evaluation indicated that customers desire a range of component options and service levels that can be provided by different capacities and sizes of systems (Miller et al., 2000).

System specific evaluation studies have also highlighted several usage problem related aspects. For instance, the evaluation of a nine year old solar home system and street lighting system in Indonesia found that although the failure rate of street lighting systems was high, the villagers had a positive opinion about these systems. It further reported that technically the solar home system functioned well and the users were satisfied. In due course of time the configuration of the solar home system had changed, villagers had replaced the original lights with cheap locally made incandescent lamps and had replaced the initially installed 100 Ah capacity solar batteries with cheaper locally produced 70Ah capacity car batteries (Reinders et al., 1999).

In contrast to the Indonesian experience, the performance of a sample of five hundred and fifty five (555) lead-acid batteries taken from two thousand five hundred and twelve domestic photovoltaic lighting installed in Mexico indicated that car type batteries (representing 87% of the sample) performed reasonably well as part of photovoltaic lighting kits (Huacuz et al., 1995). Accordingly, undersized storage capacity was one of the main technical factors contributing to a rapid decrease in battery performance. Improper operation and maintenance practices due to socio cultural factors and a lack of proper user training, these recurring elements resulted in battery life being shorter than anticipated, and the subsequent disappointment of the user with respect to photovoltaic rural electrification. Local availability of spare batteries at the rural community level and their proper disposal were identified as critical issues for the sustainability of large photovoltaic rural electrification projects (Huacuz et al., 1995).

In a similar study, the failure of bypass diodes in solar battery charging stations in Thailand was analyzed. The inclusion of bypass diodes in these systems created an unexpected failure mode when villagers wrongly connected their batteries with reverse polarity. In a survey of thirty one stations, eighteen stations were disabled by burnt out bypass diodes (Greacen et al., 2001).

Some studies have highlighted component specific issues such as those linked to inverters. A project in the early eighties in France showed that users who were supplied with DC electricity through standalone photovoltaic systems were more satisfied as compared to those who were supplied with AC electricity through the centralized inverter due to unreliable performance of inverters (Claverie et al., 1994).

On the sustainability of off-grid photovoltaic systems for rural electrification in developing countries, institutional flaws have been found to constrain the sustainability of off-grid photovoltaic system in developing countries (Lyndrup et al., 2012). The sustainability of off grid photovoltaic systems for rural electrification in developing countries is mainly on regulatory issues and directly linked to lack of technical standards (MDPI, 2016). It gave examples of South Africa, Ghana and Bangladeshi were studies were done and revealed that lack of technical standards for photovoltaic systems led to dissatisfaction caused by poor system performance and ultimately to a negative promotion of photovoltaic systems, it also reduces the quality of the system and may also inflate the cost. The quality of energy products in the market can vary significantly. For example fake solar products often overstate the capacity of systems which can lead to misuse and subsequent breakage giving solar systems a bad reputation (Laura et al., 2012).

Studies have shown that the scarcity of experts or trained personnel in renewable energy can affect the sustainability of off-grid photovoltaic systems (Ilskog, 2008). The project have to engage dedicated staff with technical knowledge and experience in solar PV systems to enable the staff to correctly anticipate the possible challenges and find suitable solutions (Mubanga, 2016). The lack of trained technician's leads to poor installations e.g. wrong cable sizing, use of uncertified components and under sizing of the photovoltaic systems due to erroneous power capacity estimations.

Affordability of electricity is a key issue in rural Zambia. This can be mitigated by providing options to facilitate end-user access to electricity service, including targeted subsidies and deferred payment scheme that could pre financed, either directly by service providers or through a micro finance institution. A sound business model should be developed for both standalone systems and mini grids in order to increase the viability and sustainability of decentralized renewable energy projects and improve access to electricity services in rural Zambia (IRENA, 2013). Since the provision of electricity to remote off-grid communities is not just a business but a social intervention, customers must be screened to identify their willingness to pay. Consumers should have a mind-set of knowing that without fulfilling the obligation of paying for their bills the solar plant would close down (Mubanga, 2016).

Solar photovoltaic systems have a significant health and environment benefits in rural areas. Since SHS and SMG have a minimal installed carbon footprint and solar energy is in almost in exhaustible supply, solar photovoltaic systems have a positive environmental impact than fossil and biomass fuels as stated by (Ehsanul et al., 2017).

Apart from the operative problems which have been studied, benefits of photovoltaic systems installations have shown to bring about develop in rural communities. Access to electricity offers benefits to development through the provisions of reliable and efficient lighting and telecommunication service (Kaygusuz, 2012). There is also a notable importance of Photovoltaics in the improvement of education in households and communities. Buragohian (2012), in her Impact of Solar Energy in Rural Development in India ; provides that getting light for children for study at night might result in major improvement in their education performance, while ESMAP (2002) see village electrification important for lighting of schools for better education attainment. According to ESMAP reports, village electrification enables the application of ICT for better education.

The above empirical studies show some of the solar energy technology misfortunes which are related to the operation of SHS and SMG, and positives of these installations in rural communities. Their view shows that a lot have been said and studied globally from different perspective on how solar photovoltaic technology can be developed and Zambia being among them.

However the literature review does not show how the SMG and SHS have performed so far in rural Zambia. To this reason this study has therefore addressed this gap in focusing on the assessment of the operatives of the SMGs and SHSs from the time of their commissioning to date by addressing the economic activities in project areas, sustainability and affordability of these technologies, the cost of the investment, O&M issues, regulatory and standards, limitations and merits of these technologies and developmental issues brought about by the presence of solar systems.

2.3 Conceptual Framework

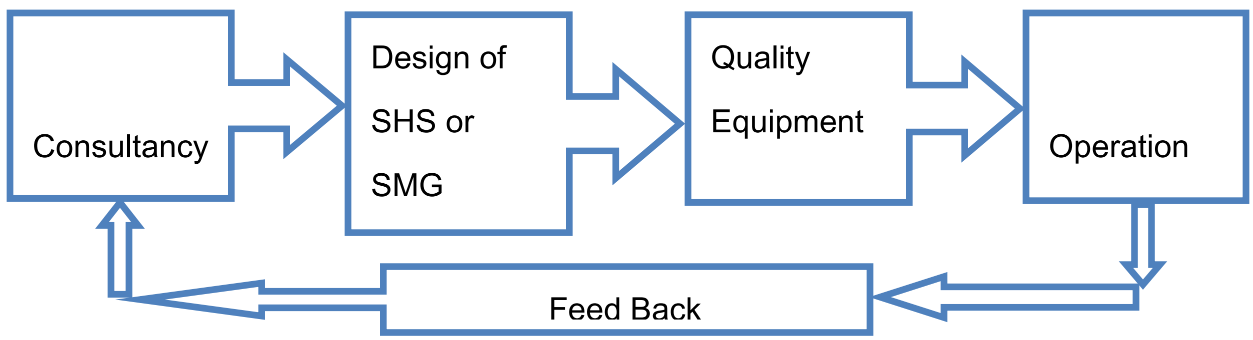
Photovoltaic and other renewable energy technologies can contribute to the economic and social development of millions of people in the world who do not have access to electricity for lighting, clean water supply, primary health care, education and other basic services.

Theoretically, solar PV could satisfy global electricity demand thousands of times over yet its potential remains unrealized because its current performance renders it more expensive than conventional sources. Though solar PV is little far from being economical in comparison with conventional fossil fuels to provide electricity, they can be cost competitive in remote areas where it is uneconomical to extend the grid line.

In line with stand-alone solar PV systems, solar mini grids and solar home systems can make a positive contribution to the sustainability of rural communities in that do not have access to electricity grid in developing countries.

For this reason a good design of solar home system or solar mini-grid will operate at expected optimum results of the designer. In this context “good” is defined as having the required qualities, of high standards, satisfying or well behaved manner.

With this in mind a solar home system and solar mini grids have to be designed and installed in such a manner that they are of quality equipment’s/components, so as to ensure sustainability of the systems. Figure 1 is the conceptual framework diagram.



Conceptual framework diagram

2.3.1 Consultancy

Before any installation is to be undertaken, there is need to consult an expert in solar photovoltaic systems. This expert is expected to come up with a design that will meet the specific energy requirements that will be required by the solar mini-grid or the solar home system. The expert will size the system by determining the number of the required solar modules, battery capacities, and capacities of the inverters and the charge controller ratings. The expert also expected to work out the quantities of materials needed for the local grid network construction.

The expert will also site the area in order to come up with the location of the power house and solar module array site in case of a solar mini-grid. In terms of a solar home system, the expert is also required to advise on the orientation and position of the solar modules, i.e. on roof top or pole mounted. He would also recommend the size of cables as per applicable standards.

2.3.2 Design of Solar Home System

The design of the solar home system will mainly consist of the following equipment;

- Solar module for generation of power
- Charge controllers for regulation of voltages between the solar modules, batteries and the load

- Inverters for converting the direct current voltage to alternating current voltage

2.3.3 Design of Solar Mini-Grid

The design of the solar mini-grid is similar to that of the solar home system, the only difference is that it will consist of;

- Solar modules array for generating power
- Charge controllers of larger amperage ratings regulating the voltages between the solar module array, larger battery bank supplying the load
- Inverters of larger power ratings converting the direct current voltage to alternating voltage
- A power house where the charge controllers, inverters and battery bank are housed
- A local grid network

2.3.4 Quality Equipment

Since most installations are provided with quality equipment at inception, problems start a few years after operations. This is mainly due to lack of maintenance, properly trained personnel to handle the equipment and lack of quality equipment on the local market. In certain cases these projects do not include replacements of broken down equipment in there terms of reference, this is entirely left to the recipients.

The quality of the local equipment has to be monitored to ensure that the market is not laden with low grade equipment. The issue of testing the local market products has to be enforced to ensure that standards of the equipment supplied are of high quality or meet the required standards.

2.3.5 Operation

A solar mini-grid or solar home system can only operate to the expected standard if the quality of its components is not compromised. A good system will last for a long time if the following items are observed;

- Trained personnel
- Routine maintenance
- Continuous training of solar technicians
- Well-designed system
- Quality equipment

2.3.6 Feedback

Monitoring of the photovoltaic systems will be essential to enable the consultant evaluate the performance. This can be done by remote monitoring of various parameters such as the supply voltages, module temperatures, occurrence of electrical faults by use of mobile phone or the internet.

Chapter 3: Methodology

3.0 Introduction

The chapter shows and explains the research procedures which were applied in carrying out the study. The two solar mini grid installations in rural Zambia were visited. These were Sinda Solar Mini Grid and Mpanta Solar Mini Grid, where data was collected to describes how the research objective where to be reached and achieved under the study. The chapter discusses, Study Design, Research Instruments, Data Sources, Data Collection and Data Analysis.

The study being a descriptive research where a survey approach was used to collect data, a purposive sampling was done with a sample size of thirty by issuing questionnaires with closed pre-coded questions to make it simple for the respondents and analysis purposes. Also questionnaires were issued to persons managing the solar mini grids. The nature of the study was explained to respondents, and the respondent's confidentiality of information was rest assured. Respondents were provided with detailed instructions as on how to answer the questionnaires. The respondents were purposively picked which included civil servants, shop owners, small scale farmers, fishermen and businessmen; a personal interview was done in assessing the loads applied on the SMG or SHS and how they were performing. Another interview with the managers of these SMG was done, although in Sinda management denied to be interviewed on the configuration of the SMG.

3.1 Study Design

Research design is a plan or structure within which research is conducted. It constitutes the plan for the collection, measurement and analysis of data. According to Gay and

Airasian (2000), a design is a general strategy for conducting a research study. The nature of the hypothesis, the variables involved, and the constraints of the real world all contribute to the selection of a design (Kothari 1988).

The exploratory research design and descriptive research was used for the purpose of this study. Exploratory research helped the researcher to understand the theories that supports solar mini-grids and solar home systems.

Descriptive research was used to describe the technical operation of solar-min grids and solar home systems configurations. This enabled the research to understand the designs of solar mini-grids and solar home systems.

3.2 Research Instruments

Field trips were undertaken in the two selected areas were solar mini grids are present for data collection. The focus was on solar mini-grid management, customers who are supplied by solar mini grids and those who own their own solar home systems in these areas.

Questionnaires were used to assess solar home system owners, managers of solar mini grids as well as their customers and photos were taken to show the actual scenarios prevailing in these project areas.

Then a desk work was followed by analyzing the data collected from the field using statistical package for social sciences (SPSS) software for statistical calculations and plotting of graphs and charts.

3.3 Data Sources

Since the study was exploratory and descriptive in nature, it was dependent on both primary and secondary data. Also the methods included survey, unstructured interviews, documents gathering, direct observation and informal conservations. Direct observation was used as a supportive technique to complement the information from interviews and questionnaire surveys. A camera was used to take relevant pictures deemed necessary to the research.

The source of primary data was from the management of the solar mini-grids, their customers and solar home system owners.

The source of secondary data comprised that from Department of Energy (DOE), Energy regulation Board (ERB), Bureau of Standards (ZABS), Rural Electrification Authority (REA), Non-Governmental Organization (NGO'S) and solar energy companies.

3.4 Data collection Procedure

According to Cohen and Manion (2007), the researcher must use the chosen data collection tools and techniques systematically and properly in collecting the evidence. Observations and data collection settings may range from natural to artificial, with relatively unstructured to highly structured elicitation tasks and category systems depending on the purpose of the study and the disciplinary traditions associated with it.

To get respondents suitable for the study, a purposive sampling technique was applied as stated by Bernard (1990) and Devine and Heath (1999). It was done in two stages, the first one was the selection of the places where the study was to be conducted. The main criteria were that there should be one, an existing SMG operated by GRZ and another privately operated. In that regard, Mpanta and Sinda were purposively selected as the villages with SMG's. In the second stage, purposive selection of the respondents for this study was done with the help of managers of the SMG who identified these respondents.

Data collection started with the researcher acquiring of permission from authorities in charge of the research areas. This research required collection of data from different sources so as to make conclusions and recommendations. The sample comprised of solar mini-grid customers, solar mini–grid managers, those who own solar home systems and those who are connect to solar mini-grids and own solar home systems.

This was followed by making interviews with the customers of the solar mini grids, solar home system owners and managers of SMGs. At each research site, the researcher followed the same sequence in the collection of data.

3.5 Data Analysis

According to Miles and Huberman (1994), data analysis may commence during interviews or observations and continue during transcription, when recurring themes, patterns and categories become apparent. Once written records are available, analysis involves the coding of data and the identification of prominent points or structures. Having additional coders is highly desirable, especially in structural analyses of discourse, texts, syntactic structures or interaction patterns involving high inference categories leading ultimately to the quantification of types of items within categories. Data reduction may include quantification or other means of data aggregation and reduction, including the use of data matrices, tables, and figures. Also Patton (1990) also suggests that data analysis starts during data collection and that this continues throughout the study.

The qualitative approach was used to analyze data that was collected from interviews. The study comprised four research objectives with four corresponding research questions. Thus on the basis of each research question, the data collected were put into identified themes and sub themes after which interpretations and discussions were made.

A quantitative analysis was also done on the LCOE produced by the SMGs and compared with the prevailing cost of electricity being charged by the SMGs. A technical solar home system design was also undertaken in the appendix to calculate the number of solar panels, the battery capacity and number of batteries needed, the size of the inverter and charge controller needed to support the available loads. This design helped to assess whether the cost of the SHS can be afforded by comparing with their economic situations of these areas.

Since the analysis was both quantitative and qualitative, it included plotting of bar charts, pie-charts and percentage analysis.

The two types of software which were used are the Statistical Package for Social Sciences (SPSS) and Microsoft Excel.

Chapter 4: Results

4.0 Introduction

This chapter discusses the findings which were obtained in Sinda and Mpanta villages concerning the findings of the questionnaires and sub themes derived from research objectives and their corresponding questions. The presentation of findings also takes into account attitudes, views, suggestions, and assumptions of the various categories of respondents that participated in the research.

4.1 Results

This is the reflection of the solar mini grid customers, managers and solar home system owners concerning the demographic information, load assessment, performance assessment, socio-economic and education level for the project areas.

4.1.1 Sinda Mini Grid

Sinda village is about 427km from Lusaka and is currently being supplied with power from the solar mini grid within a radius of one kilometer. The solar mini grid has been in operation from 9th May, 2017 and its being managed by Muhanya Solar Company. Currently there are 60 connected customers and the company is in the process of connecting 63 more clients to the solar mini grid.

This solar mini grid of 25kW capacity consists of two arrays of forty 305Wp solar panels. There are four strings of ten panels which are connected in parallel to make an array of forty panels. There is also a power house which houses inverters, charge controllers and a battery bank. The power produced is supplied to clients through a local grid network of one kilometer radius. During the day, the power from the solar modules is supplied direct to the inventers and at night it’s supplied from the batteries to the inventers.

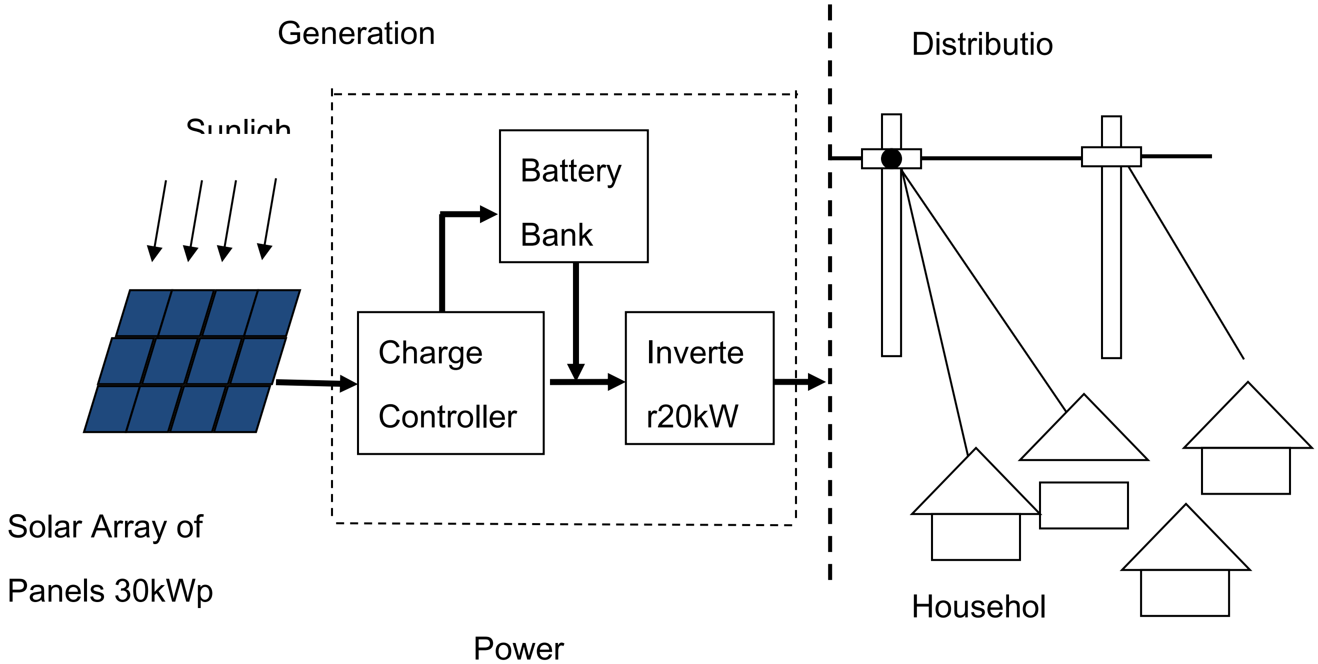


Figure 4. 1: Sinda solar mini grid configuration

4.1.2 Demographic information

Out of the 30 respondents interviewed, they comprised of 57.14% women and 42.86% men as can be seen in chart below. At the time of this research a total of 60 housing units where connected to the solar mini grid.

The village comprises of 82.1% of married people, 7.1% single people, 3.6 % divorced and 7.1% widows. The majority of the population occupation is farming with a few business persons. The standard of education amongst the respondent is not so high since the highest levels of education attained is secondary school.

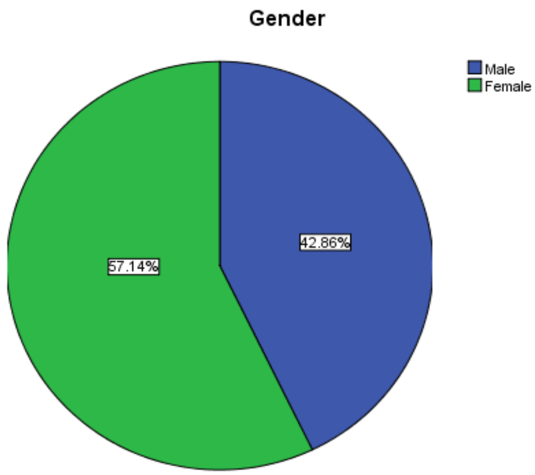


Figure 4. 2: Gender representation of respondents in Sinda village

4.1.3 Economic activities

The majority of the community are farmers, meaning that most of the respondent's income is entirely dependent on the sale of farm produce. Farming represents 78.57% as the major economic activity followed by those who do business and farming at 10.71% with those who are entirely in business at 7.14% and other economic activities at 3.57% as represented in the figure.

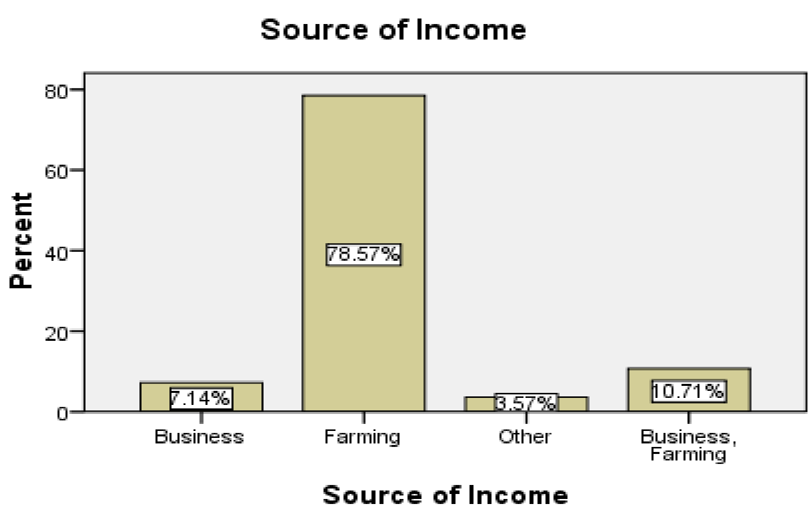


Figure 4. 3: Source of income in Sinda village

The distribution of respondent's income sources by gender is that, those who are involved in business are evenly distributed at 3.6%, those involved in farming are at 46.4% women and 32.1% men. The ones involved in farming and business stand at 3.6% men and 7.1% women. For other income activities the representation is 3.6% women as shown in the figure.

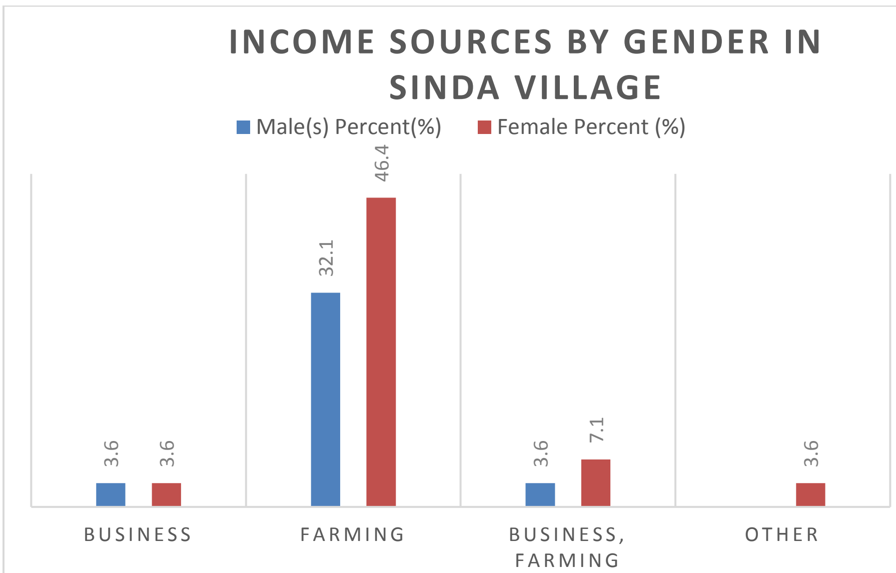


Figure 4. 4: Distribution of income sources by gender

The farming is not done at large scale but at subsistence level. Their annual earnings range from K6000 (US$ 580.91) per annum to K30000 (US$2904.53) per annum as shown in the figure.

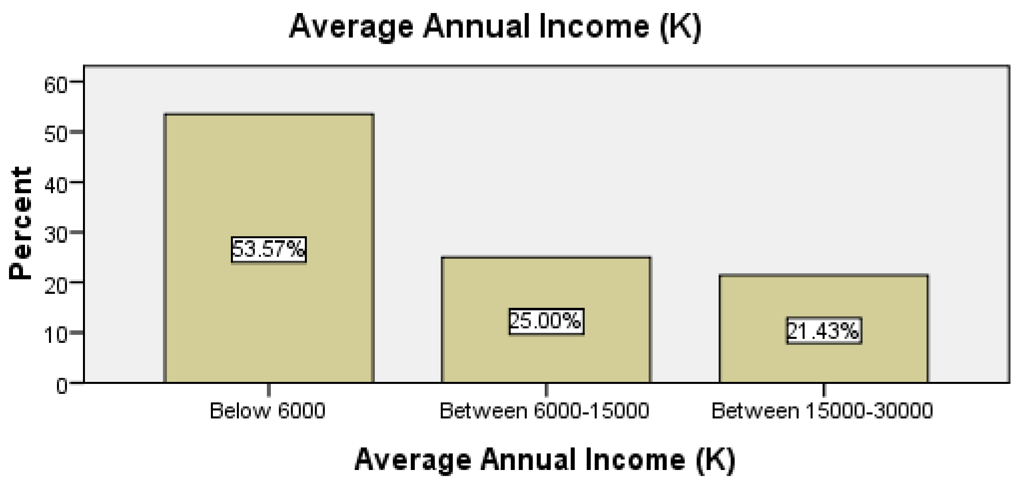


Figure 4. 5: Average annual income in Sinda village

The gender representation of average annual income is composed of those earning below K6000 with 32.1% females and 21.4% males, and those earning between K6000 to K15000 with 14.3% males and 10.7% females. The earners of between K15000 to K30000 are at 14.3% and 7.1%, males and females respectively as shown in the figure.

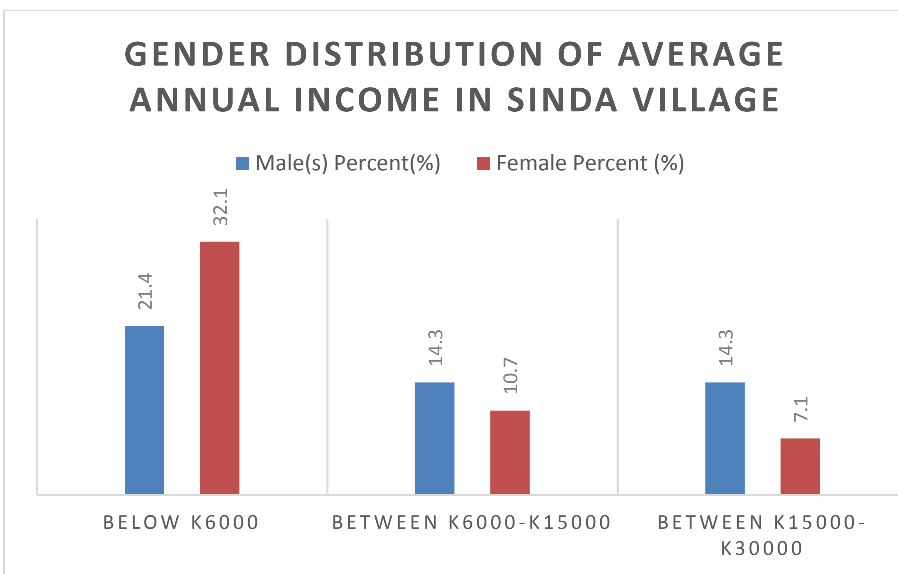


Figure 4. 6: Gender distribution of average annual income

4.1.4 Cost of Electricity

The electricity is being charged at a tariff of K5 (US$0.484) per day. Essentially this tariff translates to K150 (US$ 14.523) per month for a client who is connected for 30 days. This tariff is advantageous to clients with appliances such as fridges, television sets, musical systems, lighting bulbs etc. whilst those with only lighting bulbs, feel that the electricity is expensive. Management feels the tariff is cost effective to sustain their day to day operation of the solar mini grid but not substantial enough to cover for the purchase of equipment such as batteries or inverters which are more expensive. However the majority of the respondents are happy since the mode of payment is Pay-As-You-Go meaning that they are able to pay what they can afford. This has been managed by installation of prepaid meters. These meters record each micro-payment and instantly turn off their product when the credit is used up.

Figure 4. 7: Picture of installed prepaid meter in Sinda village

The 60 housing unit are connected to the solar mini grid and five of respondents household have solar home systems. Those that have solar home system are mainly using their systems as backups in case they are unable to pay for power from the mini grid.

4.1.5 Cost of Investment, Operation and Maintenance

The Sinda solar mini grid was installed at an investment cost US$ 133,700 Zambia Daily Mail (2017). This cost was inclusive of the construction of a local grid network, the power house, solar array structure and purchase of all equipment.

The operation and maintenance costs are projected at 10% of the investment costs and other overhead costs are also estimated at 10%. These overhead costs are incurred from the running of the day-to-day operations of the solar mini grid. It was calculated that the levelised cost of energy produced by the solar mini grid is 0.1021 US$/kWh, as shown in Appendix A1.

However, if one is to invest in the solar home system, a technical system design was undertaken by considering the common appliances which are used by clients with the results shown in Appendix A2. This system design was performed to help come up with a true cost reflection of the solar home system by considering a client with all the appliances from their load assessment. The cost was then determined by considering the current market pricing of the PV equipment which was arrive at above K 7450 as initial investment.

4.1.6 Operational Assessment

The general feeling of the population is that the solar mini grid has been operating effectively since inception. The reason for this good performance is attributed to the company's recommendation of limiting the power ratings of the appliances to be used. Heating appliances such as stoves, ironing iron, electric kettles and heaters are not allowed to be used. The recommended appliances are LED bulbs, Hi-Fi systems, fridges, television sets and decoders. These appliances range from power ratings of 5-100 W.

The solar home systems which are available within the community are plug-and-play systems and self-customized. These systems are already sized by the manufacturer for specific loads, for example certain systems are sized to light five bulbs and a television set and others are just for lighting purposes only. These systems are integrated meaning that the charge controller, inverter and battery bank are assembled into one component. The self-customized systems are those bought by individuals from dealers without proper sizing.

4.1.7 Load Assessment

The type of load which is connected to the SMG by the customers is in different combinations according to the type of appliance the respondents own. There are those respondents who use the SMG for lighting only, others for lighting and television, others for lighting and hi-fi stereos, some for lighting, television and hi-fi stereo, also others for lighting, television and with decoder usage, further more others for lighting, television, hi-fi stereo and decoder usage, and some for lighting, television sets, hi-fi stereos, decoder and refrigeration. These kinds of combinations depend on what the customer is able to afford. The scenario of respondents using lighting bulbs only is 14.81%, while those using lighting and television sets is at 22.22%, those using the power for lighting and hi-fi stereo amount to 11.11%, those using lighting bulbs, hi-fi stereos, television sets and decoders amount to 16.67% of the respondents. Those using lighting bulbs, decoders and television sets stand at 7.41% of the respondents, the ones using lighting bulbs, television hi-fi stereo and decoder amount to 11.11% of the respondents whilst users of lighting bulbs, television sets, fridge and decoders amount to 11.11% of the respondents as shown in the figure.

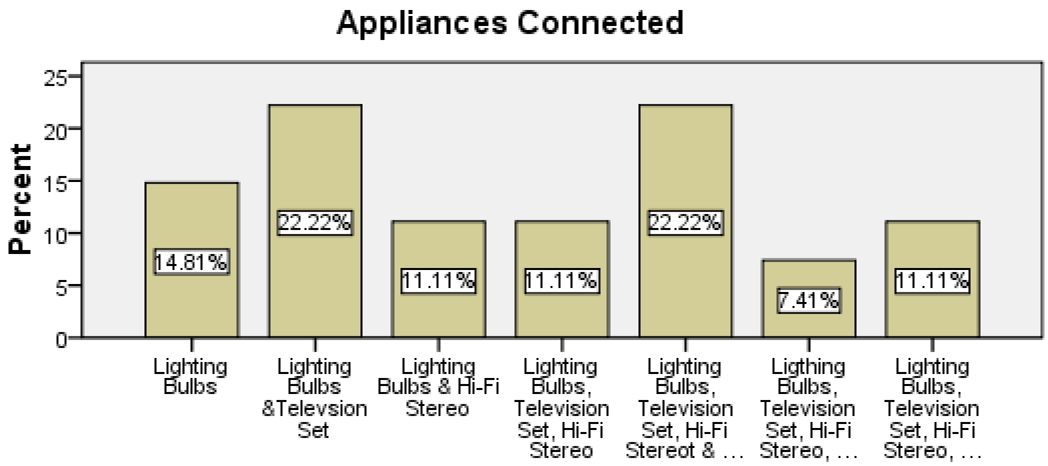


Figure 4. 8: Combination of appliances connected to the SMG/SHS in Sinda village

The distribution of combination of appliances connected to the SMG and SHS by gender vary from 14.8% of women using lighting bulbs, TV set, Hi-Fi stereo and decoder whilst the males stand at 7.4%. There is also equal usage of lighting bulbs, TV set and Hi-Fi stereo at 11.1% for both gender together with the ones using lighting bulbs and TV sets. In case of those connecting lighting bulbs only 3.7% are males and 11.1% women, for lighting bulbs and stereo the distribution stands at 7.4% males and 3.7% women. Women are the most users of lighting bulbs, TV set, Hi-Fi stereo and decoders with 14.8% whilst male are at 7.4%. For those connecting lighting bulbs, TV set, Hi-Fi stereo, decoders at 3.7% for both gender, and those using lighting bulbs, TV set, Hi-Fi stereo, decoders and fridges being represented by 3.7% women and 7.4% males as shown in the figure.

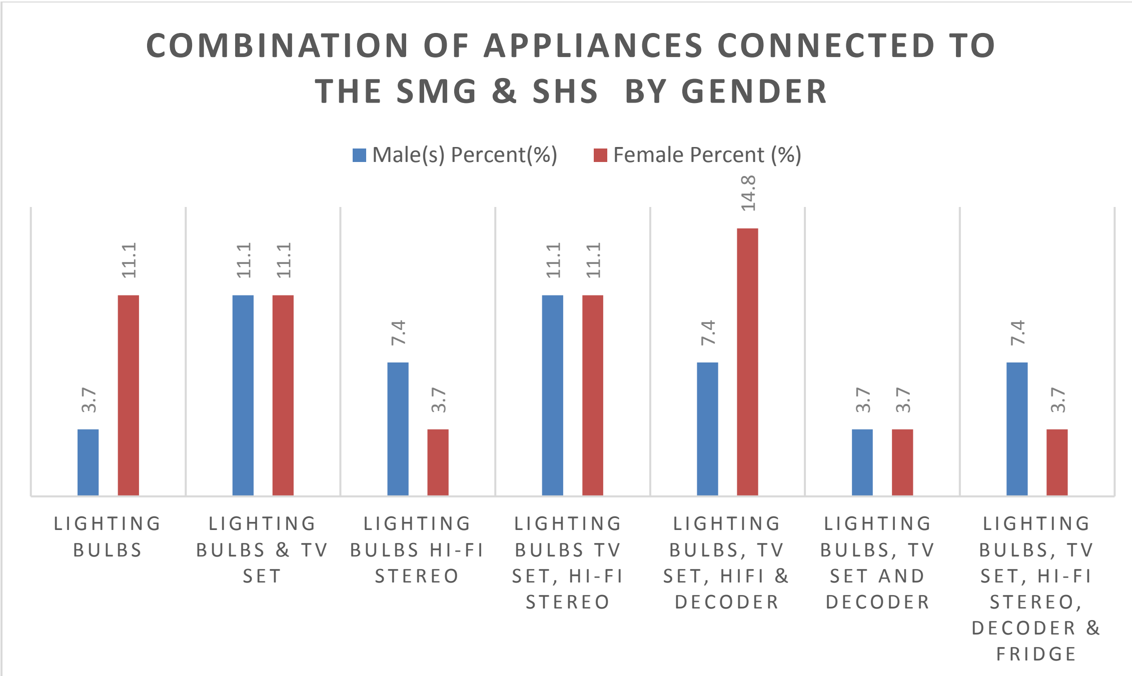


Figure 4. 9: Combination of appliances by gender

These appliances which are connected vary in their specific wattages. The fridges are rated at 80 W to 100 W, the television sets also range from 80 W to 100 W, the decoders at 15 W and Hi-fi stereos at 60 W to 80 W respectively. The LED bulbs used or allowed are 5 W which have to be bought form Muhanya Solar and are freely supplied for new customers who are connected. The graph of figure 4.1 6 shows how the appliances wattages are distributed amongst the respondents with the fridges at 11.29%, television sets at 25.817%, Hi-fi stereos at 38.71% and decoders at 24.19% respectively.

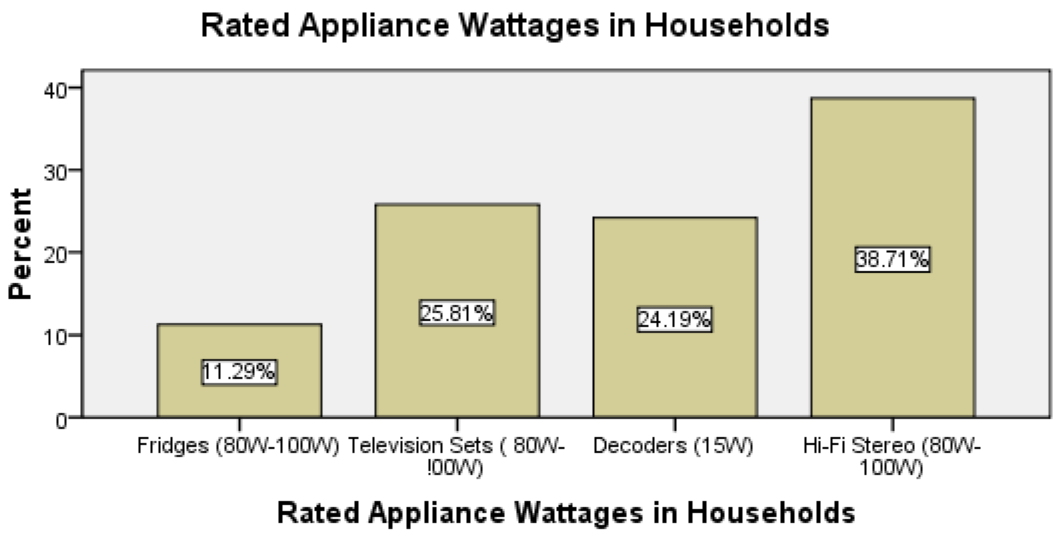


Figure 4. 10: Rated wattages of appliances in households

Generally the amount of power which is being produced by the SMG is more than enough for the 60 connected customers. The maximum load of the community is about 9.7kW and does not exceed the 18kW of power expected to be drawn by 60 households from the solar mini grid.

Among the respondents, some own SHS which they use in case they don't buy units. These SHS are bought from local solar dealers. They are either plug-and-play systems which have been sized to specific loads or those that have been self-customized by the respondents according to their load demands. The figure below shows how the usage of SMG and SHS in Sinda village. Mostly 85.19% depend on the SMG and 14.81% usually use SHS as back-up systems in case of being cut-off or unable to buy the units for power.

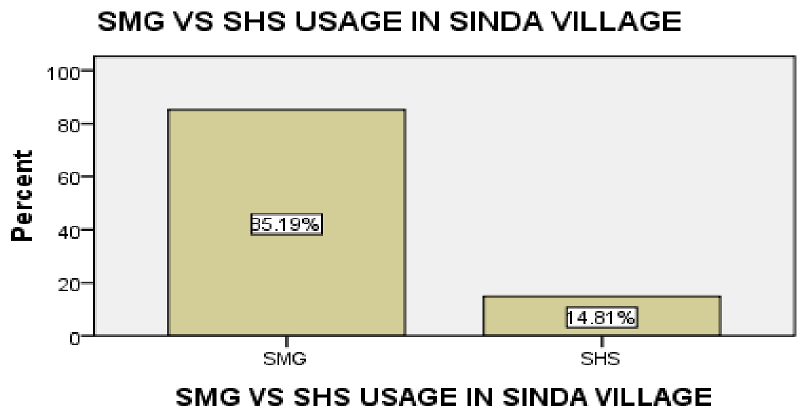


Figure 4. 11: SMG and SHS usage in Sinda village

The gender representation on the usage of SMG and SHS in Sinda village stands at 51.9% women using the SMG while 33.3% are males. The usage of SHS is 7.4% for both categories as shown in the figure below.

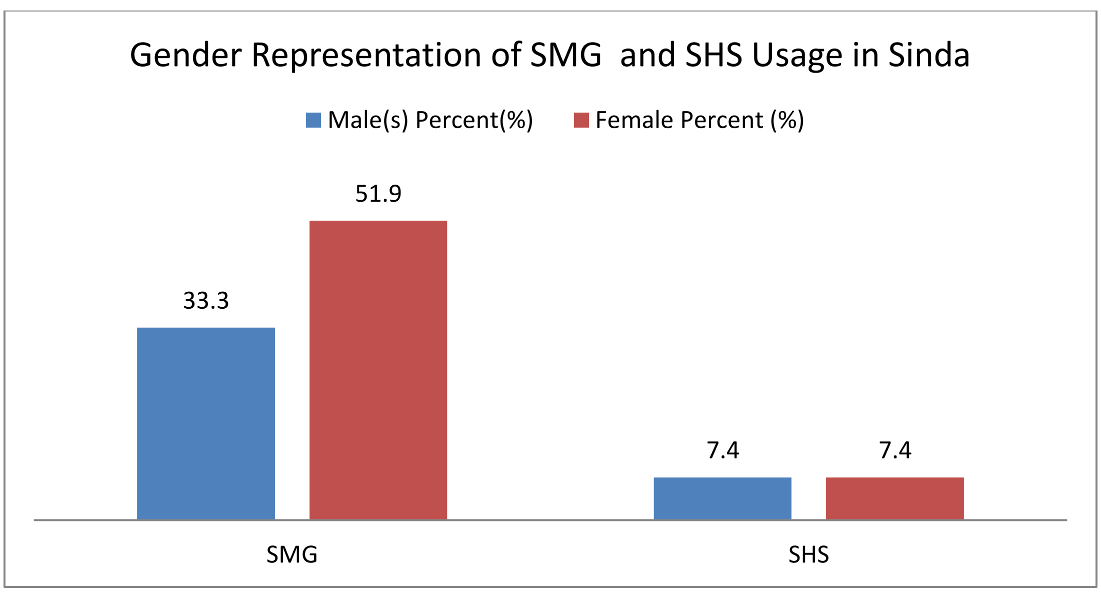


Figure 4. 12: Gender representation of usage of SMG and SHS in Sinda village

4.1.8 Socio-Economic and Education

The installation of the solar mini grid has provided an improvement on the socio-economic and education. The social aspect of the people has been improved such that they are able to get information and news through television, radio and mobile phones, since the power provided is for 24 hour. They are also able to watch entertaining program on television such as football matches. Businesses such as home shops, barbershops operate at extended hours due to the presence of lighting availability hence boosting the economic activities of the community.

(a) (b)

Figure 4. 13: (a) Picture of pay TV and (b) a home shop

The leading business in this village are home shops which stand at 41.67%, followed by mobile phone charging and bars at 16.67%, whilst the pay TV watching and tailoring are at 8.3% respectively. The figure 4.14 below shows the statistics of businesses being conducted in Sinda village.

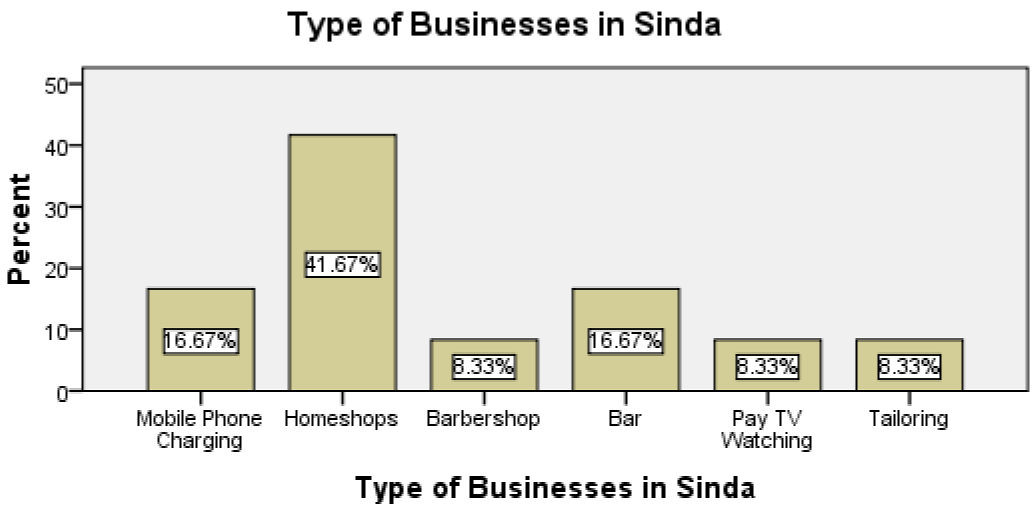


Figure 4. 14: Type of businesses in conducted in Sinda village

The general feeling of the respondents is that the living standard of the community has been uplifted. The level of children performance at school is said to have also greatly improved since school going children are able to study at night. Before the solar mini grid it is said that school going children were restricted to studying during the day. This had an effect on their performance at school since most of them were required to help with household works during the day and were also expected to help with farm works. Parents acknowledged that the coming of the solar mini grid has really helped their children at school and that their performance at school has greatly improved.

4.2 Mpanta Mini Grid

Mpanta village is about 692km from Lusaka and is currently being supplied with power from the solar mini grid of 60kWp capacity within a radius of 1.5km. The solar mini grid has been in operation from 2013 and its being managed by REA and Kafita Multipurpose Co-operative Society Limited. Currently there are four hundred and fifty connected customers.

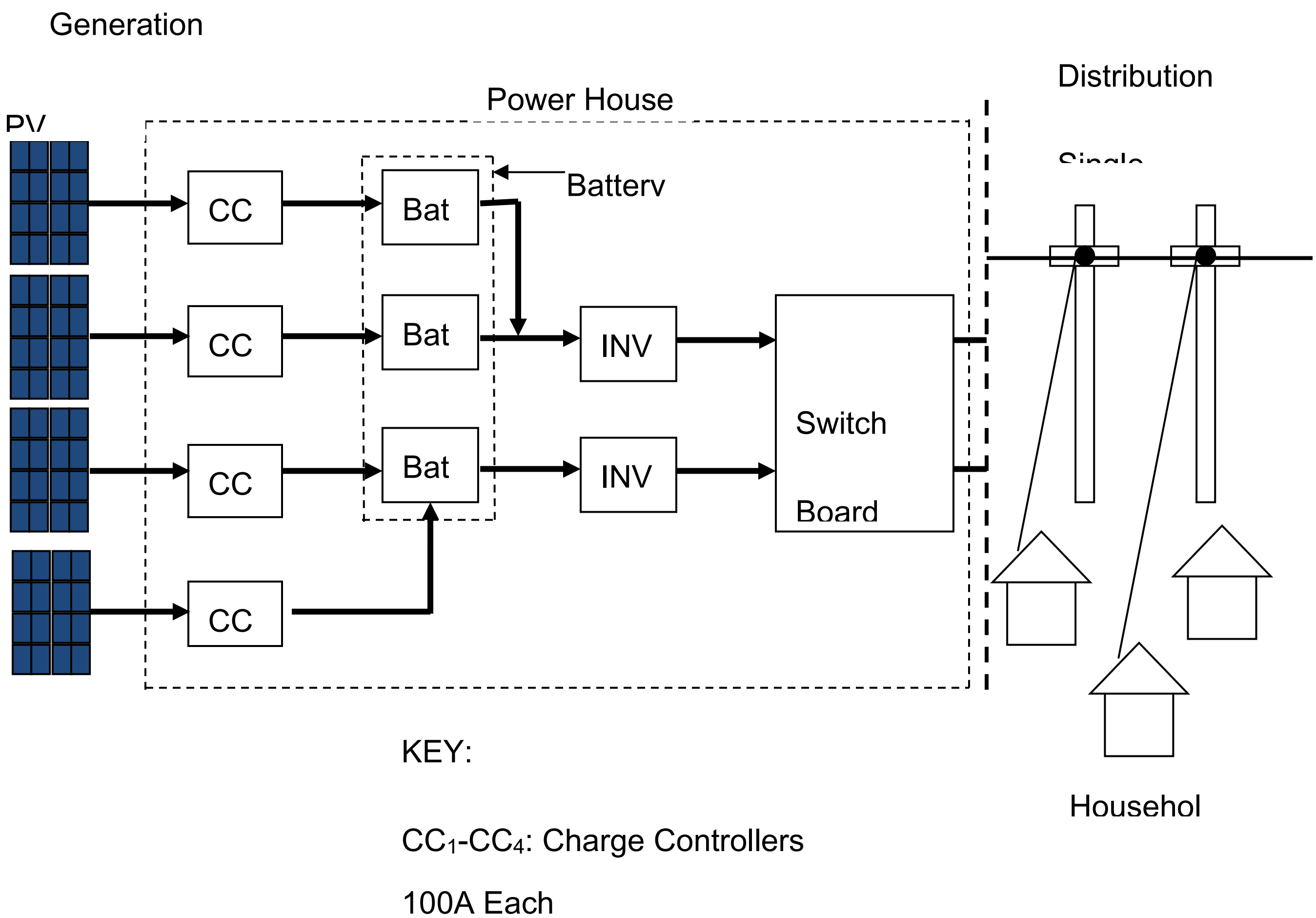


Figure 4. 15: Mpanta solar mini grid configuration

This solar mini grid consists of 300 solar panels of 200 Wp in arrays of 10 solar panels. There is also a power house which houses four inverters of 15 kVA capacity 240V ac output, two 240 VDC-400 VDC, 100 A maximum charge controllers and 5400 Ah capacity battery bank. The power produced is supplied to clients through a local grid network.

4.2.1 Demographic information

The sample of the respondents interviewed comprised 58.8% women and 41.2% men as can be seen in the figure.

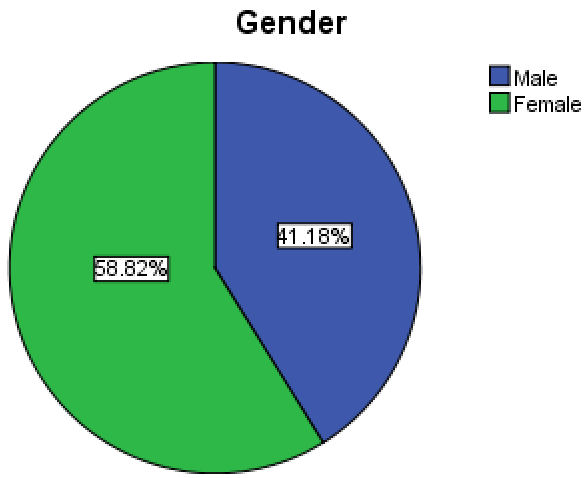


Figure 4. 16: Gender representation of respondents in Mpanta village

The sample comprises of 76.5% of married people, 14.7% single people and 8.8% widows. The majority of the respondent's occupation is fishing followed by people working in government institutions with a few business persons. The levels of education amongst the respondents show that those that are employed in government institutions have either gone to university or college whilst the rest have attained a secondary or primary education.

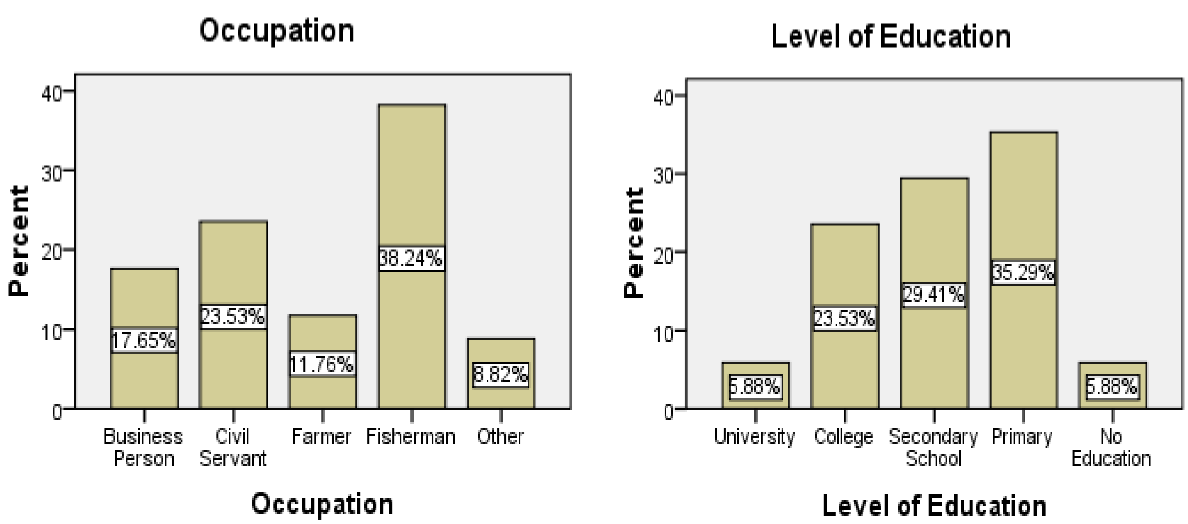


Figure 4. 17: Occupation and levels of education in Mpanta village

4.2.2 Economic activities

The majority of the community are fishermen but it is also a cosmopolitan community with teachers, health workers, clergymen, farmers and businessmen. Farming is done at subsistence level for home consumption. The main economic activity is fishing which accounts for 38.24% of the respondents, those who are employed in various government institutions and other organisations stand at 29.41% of the respondents, whilst those engaged in farming at 14.71%, those doing business activities stand at 11.76% and various economic activities at 5.85% of the respondents. The figure below shows the sources of income.

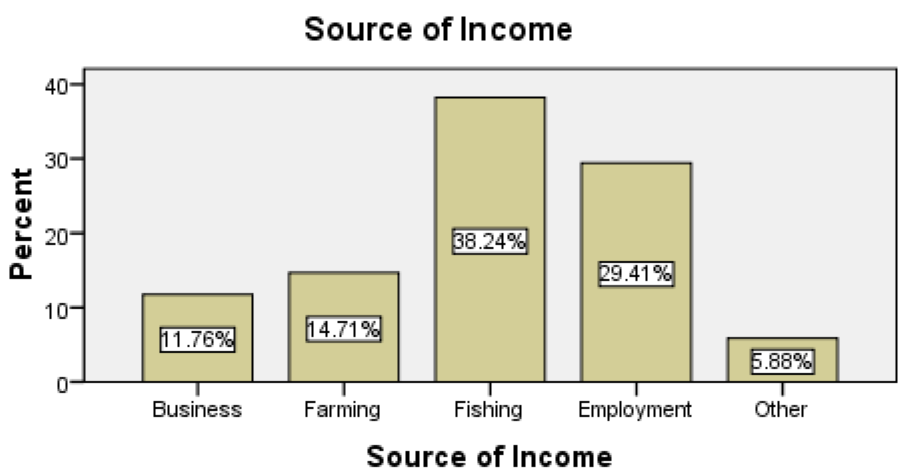


Figure 4. 18: Sources of economic activities in Mpanta village

The representation of income sources by gender in Mpanta village is categorised as follows. In fishing, 26.5% males and 11.8% are involved whilst 14.7% for both genders are in employment. Those in farming are 8.8% males and 5.9% females and in business only 5.9% for both genders, the rest are in other income source with 2.9% for both genders as shown in figure.

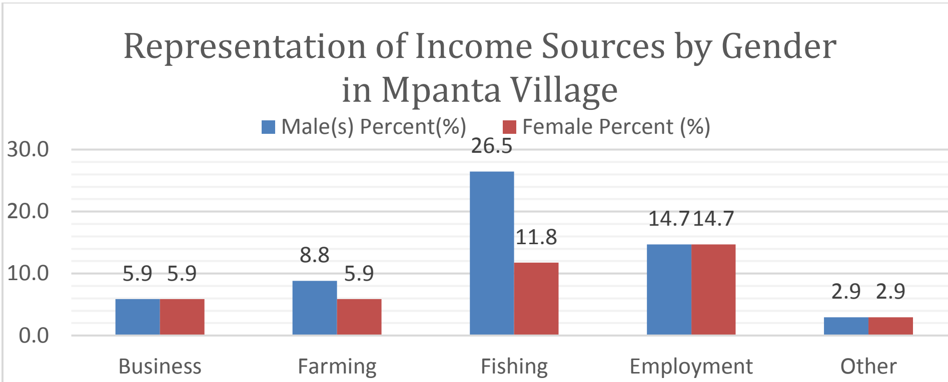


Figure 4. 19: Distribution of income sources in Mpanta village

The average annual income of the respondents vary from the range of below K6000 to above K60000 of total earning. The respondents earning below K6000 stand at 32.35%, whilst between K6000 to K15000 at 23.53%, at between K15000 to K30000 is at 14.71%, those in the bracket of K30000 to K60000 at 11.76% and those earning above K60000 at 17.65% of the respondent as shown in figure 4.20.

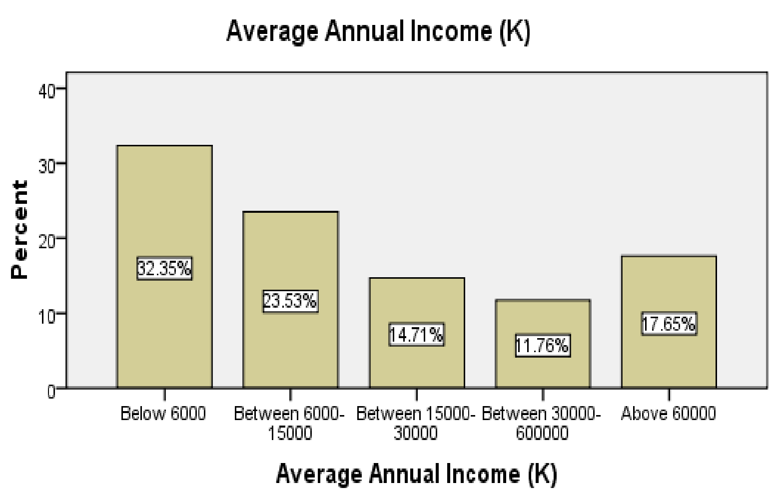


Figure 4. 20: Average annual income in Mpanta village

These average annual incomes are distributed by gender amongst the respondents is as follows; those earning below K6000 are represented by 11.8% males and 20.6% females. The ones earning between K6000-K15000 are represented by 14.7% males and 5.9% females while those earning between K30000-K60000 are represented by 8.8% and 2.9% women with 11.8% respectively resenting both genders for those earning above K60000 as shown in the figure.

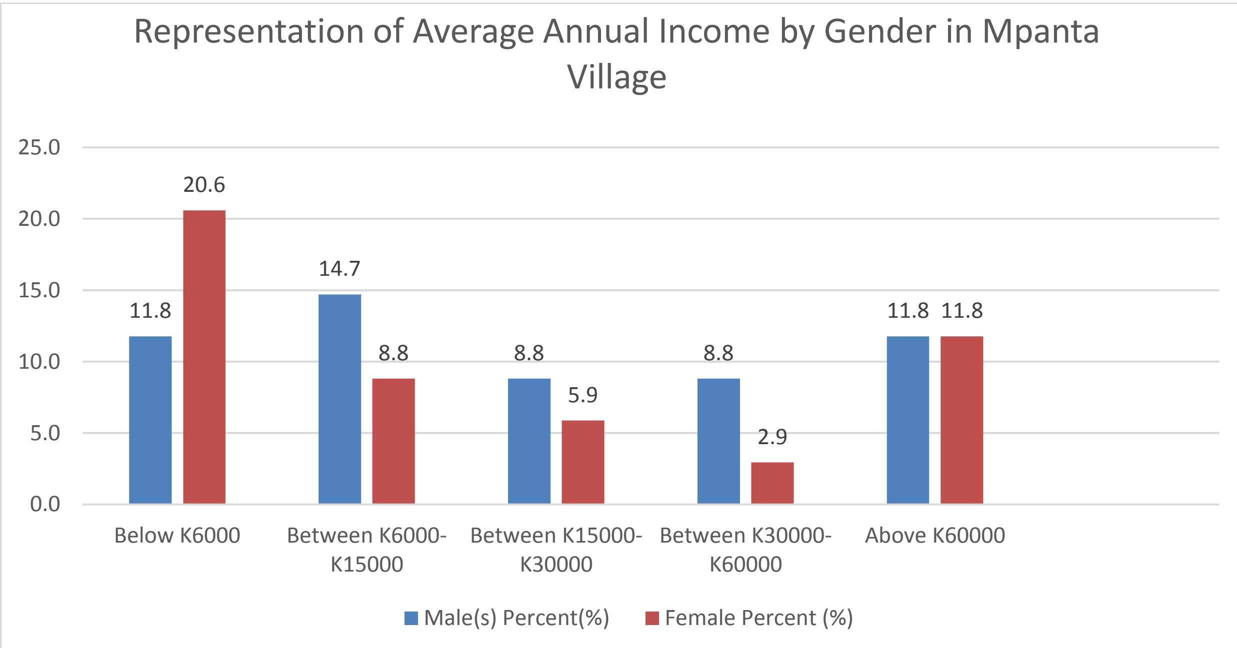


Figure 4. 21: Average annual income by gender in Mpanta village

4.2.3 Cost of Electricity

The cost of electricity is being charged at fixed tariff depending on the number of rooms a building has for residential clients, lighter commercial and social services. Table: 1 shows the costing of the charges available. This fixed tariff depends on how big the house is and the appliances such as fridges, television sets, musical systems which a client can afford to use. Those that are in school staff houses, clinic staff houses pay more followed by those in seven roomed houses, six roomed houses and five roomed houses whilst those in four and three roomed house pay a relatively low tariff.

Essentially the tariff is structured in such a way that those paying K30-K35 do not have a lot of appliances to use but basically using the SMG power for lighting purposes only while those paying K50-K60 have at least a television set or a Hi-fi stereo or both plus the lighting, in case of deports its fridges and lighting only. Those in the range between K65-K70 have at least television set or a fridge, hi-fi stereo and lighting. The customers paying K100 are the ones owning a television set, fridge, hi-fi stereo, decoder plus lighting. The respondents paying K30/month are represented by 20.59%, those paying K35/month are represented by 14.71% and those paying K50/month are represented by 8.8%. The ones paying K60/month are represented by 35.3% whilst those paying K65/month are represented by 2.9%, for K70/month are represented by 8.8% and K100/month are represented by 2.9%. The ones using the SMG power for free are represented by 5.9% and happen to be the SMG workers as shown in figure 4.22.

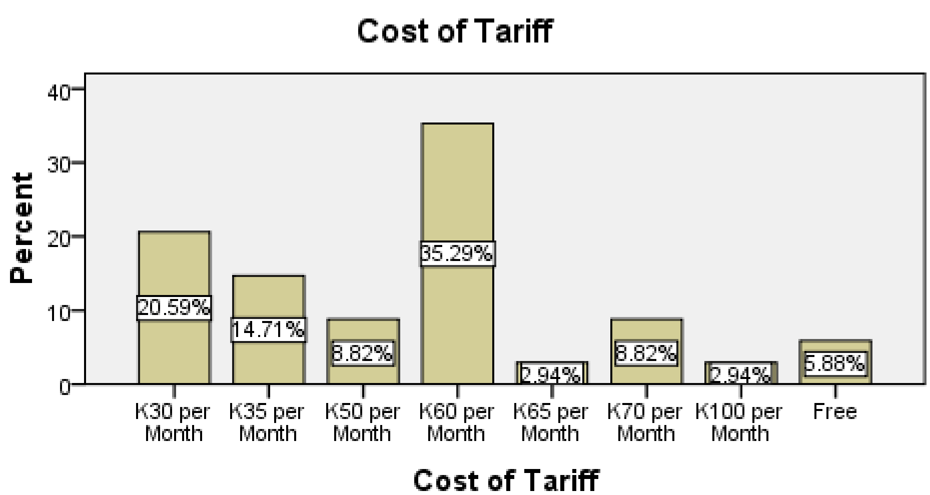


Figure 4. 22: Fixed charges in Mpanta village

The cost of tariff vary across gender representation with those paying K30/month constituting 8.8% males and 11.8% females. The ones paying K35/month constitute 2.9% male and 14.7% females, with those paying K50/month having 5.9% males and 2.9% females, and for those paying K60/month having 14.7% males and 20.6 females. In the K65/month there is 2.9% of males only, and for the K70/month having 5.9% males and 2.9% females respectively. The band of K100/month consist of 2.9% males only and those who do not pay at 5.9% males as shown in figure 23.

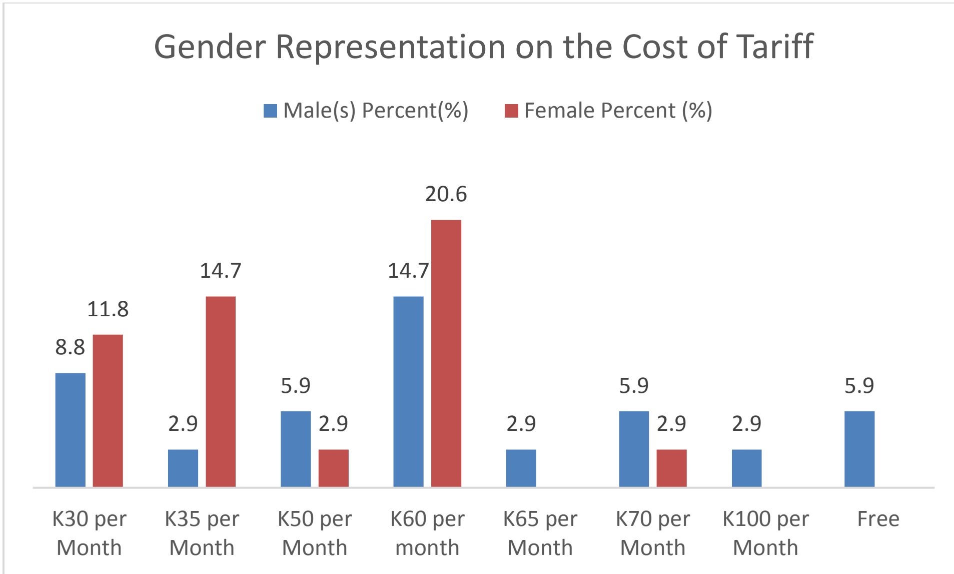


Figure 4. 23: Gender representation for cost of tariff

Regardless of the variation of the tariff being paid management feels the tariff is cost-effective to sustain day to day running of the solar mini grid and it's not substantial enough to cover for the operational and maintenance costs of the grid, like purchasing of the faulty inverter. However the majority of the respondents are happy since the tariff is largely dependent on the number of rooms of a house. Nevertheless there are plans by management to install prepaid meters once the funds are available.

Table 1: Fixed Monthly Charges in Mpanta Village

	Client Category	Fixed Monthly Charge (ZMK)	Equivalent Fixed Monthly Charge in (US$)
	Residential		
i.	Three Roomed Household	30.00	2.905
ii.	Four Roomed Household	35.00	3.388
iii.	Five Roomed Household	60.00	5.809
iv.	Six Roomed Household	65.00	6.293
v.	Seven Roomed Household	70.00	6.777
vi.	School Staff Houses	100.00	9.682
vii.	Clinic Staff House	100.00	9.682
	Commercial		
Viii.	One Roomed Shop	60.00	5.809
ix.	Two Roomed Shop	65.00	6.293
x.	Three Roomed Shop	70.00	6.777
	Social Services		
xi.	Habour Deport	50.00	4.841
xii.	Health Center	50.00	4.841
xiii.	Primary School	50.00	4.841
xiv.	Churches	50.00	4.841

Table 1: Fixed Monthly Charges; Source Mpanta Solar Mini Grid Management

(Exchange rate used US $1: ZMK 10.3287)

The cost of energy which is being charged in Mpanta is not cost effective, they do not reflect the actual energy used by the customers. This is bound to either be advantageous to the customers and disadvantaging the energy suppliers or vice versa. In the appendix 1, it was calculated that the Levelised Cost of Energy being produced by the solar mini grid is 0.495US$/kWh.

4.2.4 Cost of Investment, Operation and Maintenance

The Mpanta solar mini grid was installed at an investment cost US$ 1,300,000 (REA 2013). This cost was inclusive of the construction of a local grid network, the power house, solar array structure and purchase of all equipment.

Management in Mpanta has drawn up a routine maintenance schedule for two hours where the solar panels are cleaned on a daily basis and any fault occurring on the grid is attended to, regardless of the daily maintenance there is also a schedule maintenance where tightening of battery connections is done, checking of electrolyte levels of batteries and others as required such as loose connections.

Figure 4. 24: Picture of solar modules array at Mpanta SMG

4.2.4 Operation

The Mpanta SMG was commissioned five year ago in 2013. At the time of commissioning 450 clients where connected and where not being charged for the service provided.

At the time the solar mini grid was commissioned, the SMG had two 15 KVA inverters which were supplying power to the community. After some time lightening destroyed one of the inverters and the SMG started to operate at half the capacity. Due to the high cost of purchasing the inverter and other accessories, management decided that all connected clients should start paying for the electricity which was being provided, this was not received well by the general populace since they were used to the free service provided initially. Currently the finances which are realized are channeled to maintenance and other operational costs.

At the time of conducting this study, the SMG was not operating at full capacity due to the fact that there is only one inverter which is in operational however REA has imported another one from oversea and it is yet to reach Mpanta.

Since one inverter is operational, management has decided to draft a load sharing schedule were supply has to be alternated to compensate the other lines which are supplied by the damaged inverter.

Despite this status, the general feeling of the population is that the solar mini grid has been operating very effective since inception. The reason for this good performance is attributed to the company’s recommendation on the limits of power ratings of the appliances to be used. Heating appliances such as stoves, ironing iron, electric kettles and heaters are not allowed to be used. The recommended appliances are LED bulbs and CFL, Hi-Fi systems, fridges, television sets and decoders. These appliances range from power ratings of 5 W to100 W.

The solar home systems which are available within the community are individually designed systems and, plug-and-play systems. These plug and play systems are already sized by the manufacturer for specific loads, for example certain systems are sized to light five bulbs and play a radio or phone charging and others are just for lighting purposes only. These systems are integrated meaning that the charge controller, inverter and battery bank are assembled into one component. However others have self-customized systems which they buy from solar dealers.

However, if one is to invest in a self-customized solar home system, a technical system design is to be undertaken. In this regard in the appendix, a designed system of the SHS was done by considering the common appliances which are used by clients. This system design was performed to help come up with a true cost reflection of the solar home from their load assessment of the respondents.

4.2.5 Load Assessment

The type of load which is connected to the SMG by the customers is in different combinations according to the type of appliance the respondents own. There are those respondents who use the SMG for lighting only, others for lighting and television, others for lighting and hi-fi stereos, also lighting and refrigeration, some for lighting, television and hi-fi stereo, also others for lighting, television and with decoder, further others with lighting, television, hi-fi stereo and decoder, and some for lighting, television sets, hi-fi stereos, decoder and refrigeration. These come in different combinations depending on what the customer is able to afford to use. The general scenario of respondents using lighting bulbs only is 16.67%, while those using lighting bulbs and television sets is at 25%, those using the power for lighting and hi-fi stereo amount to 13.89%, for lighting bulbs and fridge is 2.78%, those using lighting bulbs, hi-fi stereos, television sets and decoders amount to 16.67% of the respondents. Those using lighting bulbs, decoders and television sets stand at 5.56% of the respondents, the ones using lighting bulbs, television hi-fi stereo and decoder amount to 11.11% of the respondents whilst users of lighting bulbs, television sets, fridge and decoders amount to 8.33% of the respondents as shown in the figure 4.24.

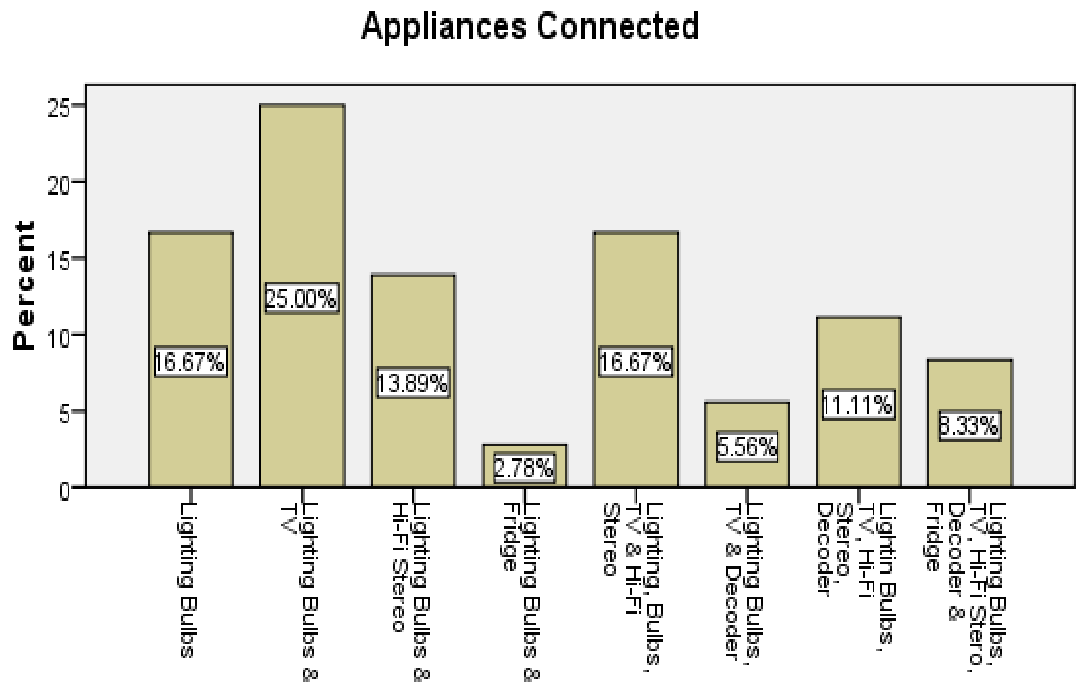


Figure 4. 25: Combination of appliances connected to the SMG/SHS

The representation of the appliances which are used in different combination by gender are as follows; 11.8% females and 5.6% males use lighting bulbs only. The ones using TV sets, Hi-Fi stereo, lighting bulbs, decoders, fridges are represented by 5.6% males and 2.8% females. Users of Hi-Fi stereo, lighting bulbs are represented by 5.8% males and 8.3% females whilst users of TV sets, lighting bulbs and Hi-Fi stereo are represented by 8.3% males and 8.3% females respectively. The users of Hi-Fi stereo and lighting bulbs are 5.6% females and 8.3% females. For those using TV sets, lighting bulbs and decoders are 2.8% for both genders respectively as shown in figure 4.25.

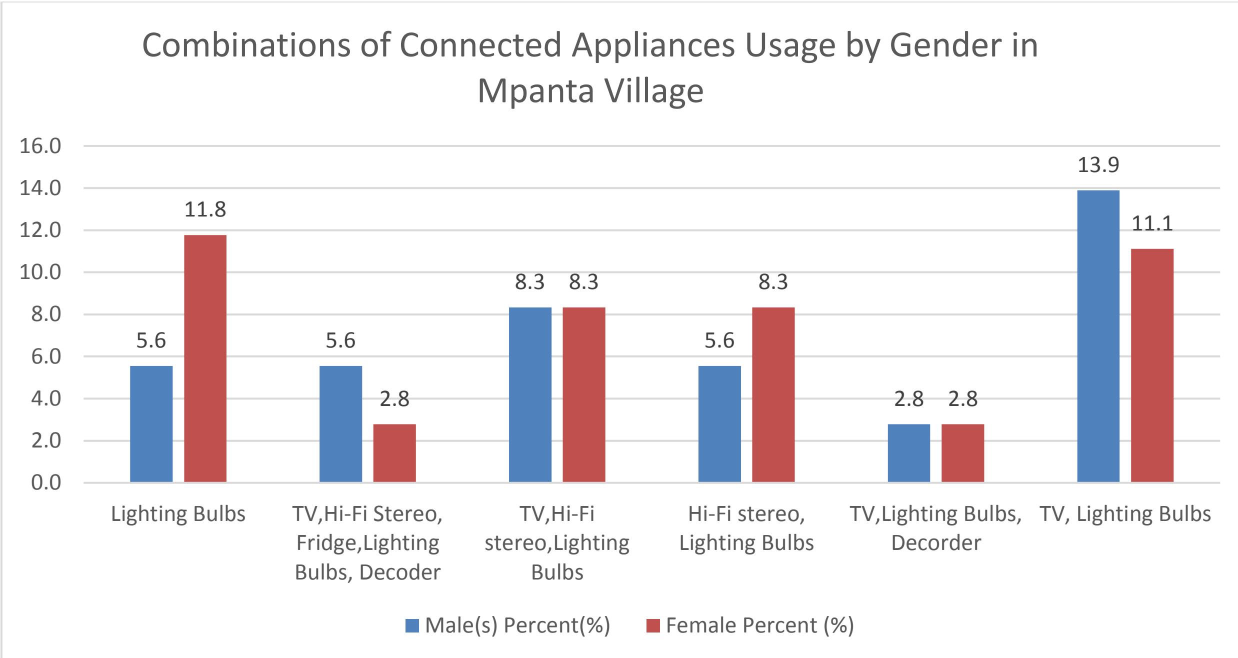


Figure 4. 26: Combination of appliances by gender

Generally the appliances which are connected vary in their specific wattages. The fridges are rated at 80W to 100 W, the television sets also range from 80W to 100W, the decoders at 15 W and Hi-Fi stereos at 60 W to 80 W respectively. The LED bulbs used or allowed are 3 W and 5 W with the compact fluorescent lamps of 15 W.

The graph of figure 4.27 shows how the appliances wattages are distributed amongst the respondents with the fridges at 6.25%, television sets at 16.67%, Hi-Fi stereos at 12.50%, decoders at 10.42%, 5 W LED bulbs at 25%, 3W LED bulbs at 16.67% and compact fluorescent lamps at 12.50%.The maximum power that a household can draw at full load does not exceed 400 W.

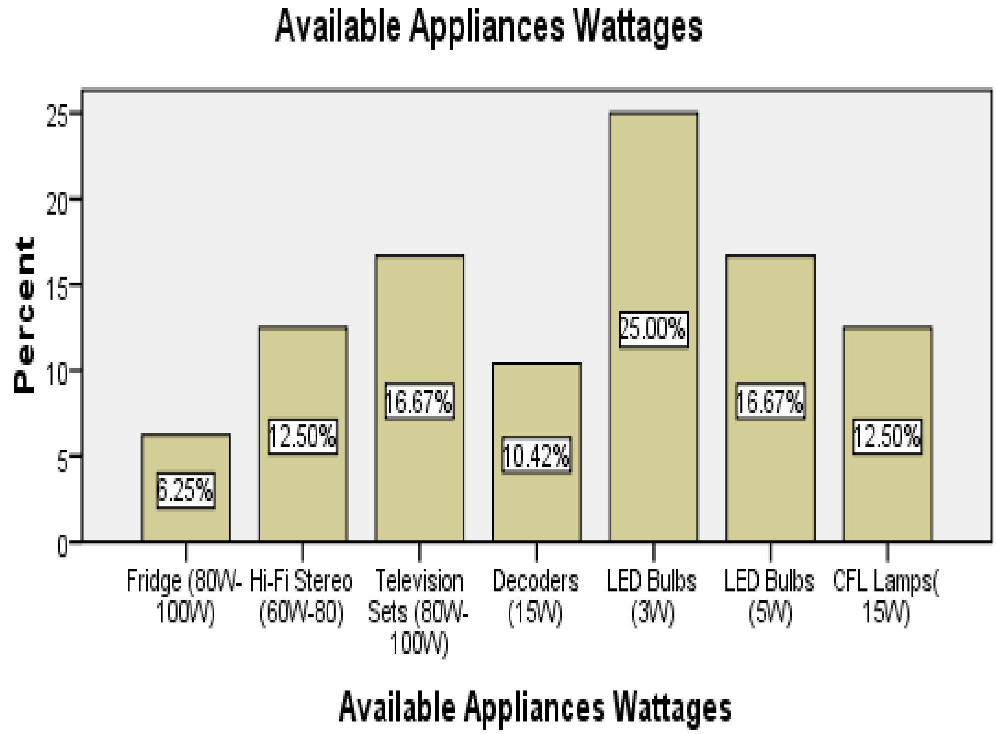


Figure 4. 27: Rated wattages of appliances in households

The solar home systems which are being used in this project area are essentially for back up purposes and are able to power televisions sets, lighting bulbs and Hi-Fi stereos. These SHS are plug-and-play and self-customized systems. Very few people are privileged to own these systems since most of them are entirely dependent on the solar mini grid. Most of those that have SHS only use them in an event that they are unable to pay and are disconnected from the solar mini grid.

The SMG usage in Mpanta is 86.49% and that of SHS is 13.51% as can be seen from the figure 4.28. The gender distribution of the users of the SMG is represented by 37.8% of males and 43.2% of females while that of the SHS is 8.1% of male and 5.4% of females as can be seen in figure 4.29.

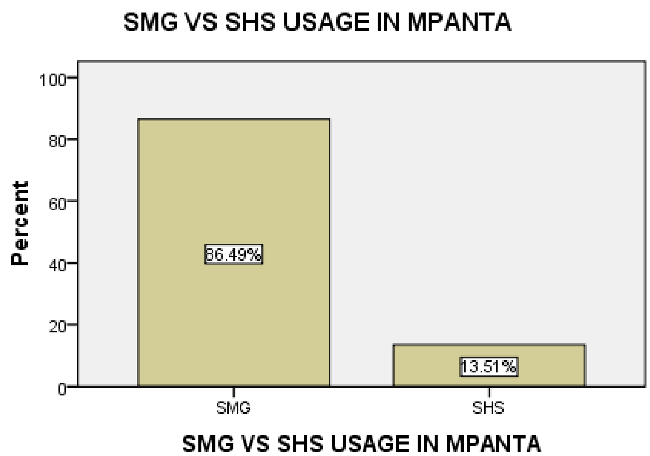


Figure 4. 28: Usage of SMG and SHS in Mpanta village

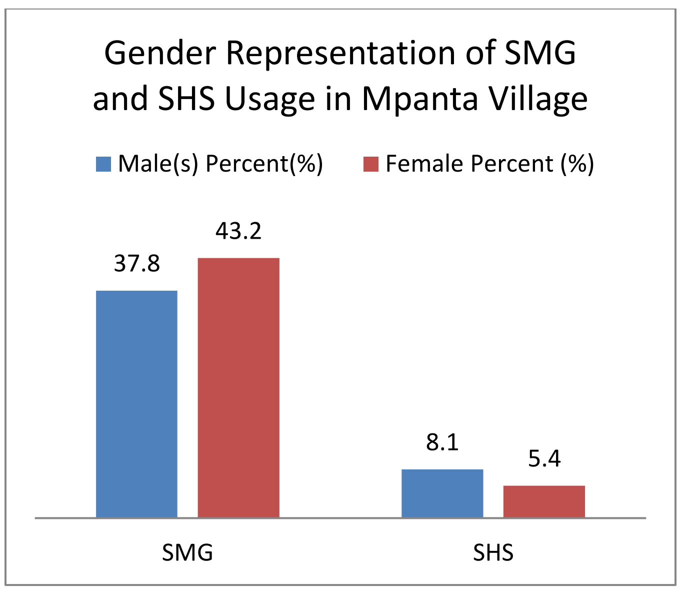


Figure 4. 29: Usage of SMG and SHS by gender in Mpanta village

The plug-and-play systems are already sized by the manufacturer for specific loads, for example certain systems are sized to light five bulbs and play a radio or phone charging and others are just for lighting purposes only. These systems are integrated meaning that the charge controller, inverter and battery bank are assembled into one component. However others have self-customized systems which are bought from solar dealers.

If one is to invest in a self-customized solar home system, a technical system design is to be undertaken. In this regard appendix A3 shows an estimated technical design of a SHS which is required to power the appliance for a respondent who wishes to invest in a SHS. The designed system of the SHS was done by considering the common appliances which is used by respondents. This system design is performed to help come up with a true cost reflection of the SHS from their load assessment of the respondents and the estimated cost which a respondent can be able pay for the investment. The prices of the equipment were obtained from solar PV local dealers in Lusaka excluding wiring and solar module mounts plus the labour.

4.2.6 Socio-Economic

The solar mini grid in Mpanta village is said to have improved the quality of life of people from the time of its commissioning in 2013. The social aspect of the villagers has been improved such that they are able to get information and news through television, radio and mobile phones. They are also able to watch entertaining programs on television such as football matches and movies.

To improve the living standards, construction of new houses is being done and others are renting houses with electricity living their traditional homes which are not in the radius of the solar mini grid supply in order to have access to electricity supply.

Figure 4. 30: A new house being constructed

There is a boom in business were people are able to own a number of businesses like home shops, barbershop, bars, commercial shops and harbor deports which have sprang up to boost the economic activities of the community. Generally, the living standards of the community is said to have been uplifted as compared to the time when there was no solar mini grid.

(a) (b

Figure 4. 31: (a) Picture of a barbershop (b) a clothing shop

The figure below shows the statistics of businesses being conducted by respondents in Mpanta village.

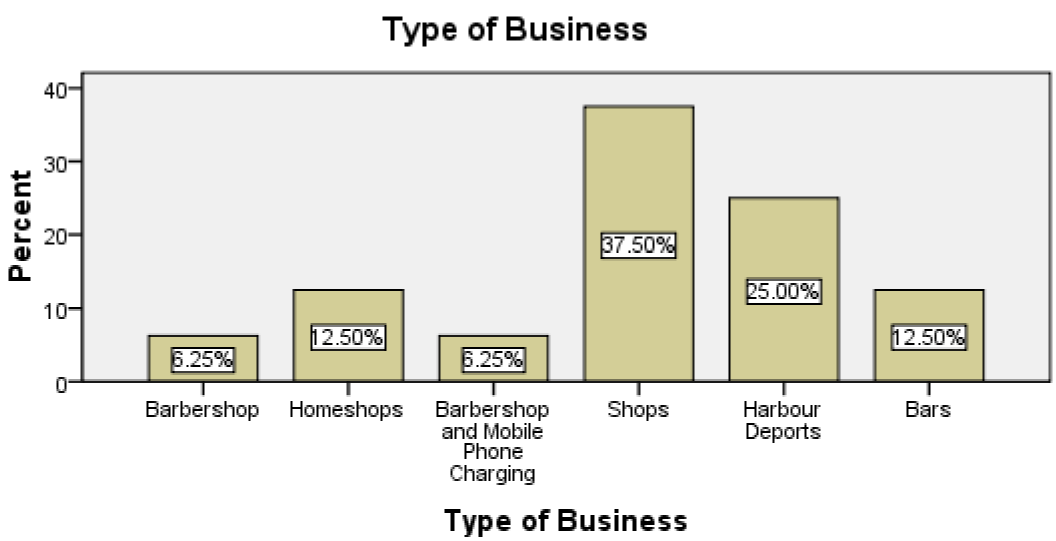


Figure 4. 32: Types of business conducted in Mpanta village

The level of children academic performance at school has also greatly improved, since they are able to study at night. Before the solar mini grid, school going children were restricted to studying during the day which was in conflicted with day to day house works. This had an effect on their performance at school since most of them were required to help with household works during the day. Parents acknowledged that the coming of the solar mini grid has really helped their children at school and their performance at school has greatly improved.

4.3 The Effective Procedures of Maintaining the Systems of SMG and SHS

Basically both solar mini grids and solar home systems have minimal maintenance procedures after installation. The procedures which are undertaken are routine maintenance and scheduled maintenance.

In routine maintenance regular cleaning of the solar panels is done three times in a month to harness the energy collection from the sun. Addition of battery water is also done to ensure equalization of the battery acid and repair of electrical faults occurring in the systems.

In scheduled maintenance planned maintenance is done under the supervision of an expert.

Since deep cycle free maintenance batteries are recommended for solar systems, the cleaning of battery terminals, electrical jumpers and tightening of all contacts are done twice in a year to prevent electrical losses between the batteries, panels, charge controllers and the inverters.

4.4 Regulatory and Standards of Solar Systems

The energy regulation board (ERB) and the Zambia bureau of standards (ZAB) are mandated to oversee the regulation and standards of solar systems through a legislative framework;

- The energy regulation Act, cap 436
- The electricity Act, cap 433
- The energy regulation (Licensing Regulation),statutory instrument No.2 of 1998

The procedure that ERB enforces as a requirement for importers of solar equipment is to obtain a license from ERB and the importer obtains a quality certification from the country of origin of each shipment. This is provided by the manufacturing company stating that their product is certified by that country's standards bureau. Since Zambian standards are based on International Electrotechnical Commission (IEC) standards which are applicable internationally, the quality certificate is checked by the Zambian Bureau of Standards at the point of entry. This license requirement is in addition to the already existing license to manufacture, install and distribute the solar equipment.

The main provisions or specifications standards in PV technology in Zambia are notably;

The **ZS 403** which looks at battery usage in the photovoltaic systems specifies the minimum requirements for batteries such as the maximum permitted Depth of Discharge (DoD) indicated approximately by the battery voltage. The Percentage Depth of Discharge looks at the energy removed from a fully charged battery expressed as a percentage of the battery's rated capacity.

The **ZS 404** which looks at the Charge Regulators for the PV systems using lead-acid batteries and specify their requirement for the charge regulator which should be fitted on all battery based PV electric systems.

It looks at the functions of the charge regulator needed in a PV system i.e.

- On how it controls the flow of current from the photovoltaic panel to the battery
- On how to control the flow of current from the battery to the load
- Indicating the state of charge of the battery

It also looks at the float charge voltage which is specified by the manufacturers of the battery used in the system.

The setting of overcharge protection in case of a switching type regulator having the High Voltage Array Disconnect (HVD) set in accordance with the specifications by the manufacturers of the battery used in the system.

The settings of the charge voltage disconnect point to be maintained within 1% over an ambient temperature range of 10^{o}C to 40^{o}C. The reconnect voltage to be set, so as to avoid rapid switching between charged and disconnect modes. A voltage of 2.1V ± 1% per cell is recommended for lead acid batteries.

The overcharge discharge protection of the battery by the charge regulator and the disconnect points to be set within specifications set by the manufacturer of the battery used in the system.

The **ZS 405** standard looks at the Photovoltaic systems design and installation code of practice. It provides requirements for design and installation of photovoltaic energy systems in domestic homes, schools, offices and industrial buildings.

The PV system sizing show how to calculate the peak power and current, daily designing load and correct amp-hour load demand, battery sizing and array sizing. It also guides on how to position the PV modules to avoid shading. It equally gives guide lines on the orientation and tilt of the modules by facing north at an angle between 15^{o} and 20^{o} to the horizontal plane depending on the latitude of location of the installation. The types of mounting or support structure needed namely roof mounting and ground mounting.

4.6 Limitations and Merits of the Solar Systems

This part highlights some of the limitations faced by SMG and SHS in there day to day operations and what remedies can be done to solve these problems.

4.6.1 Limitations

The following are some of the observed limitations which are faced by solar mini grids and solar home system installations;

- The battery is the weakest link in solar PV systems; the solar system may easily fail if specific batteries are not replaced e.g. replacing with a car battery.
- In case of the SHS, most of the systems which have been installed are donor funded and there is no money set aside for maintenance. After some time these systems become nonfunctional since owners cannot afford to replace faulty components.
- In case of SMG, tariffs have to be affordable to all users to ensure sustainability of these systems.
- Although it's a necessity to obtain a quality certificate from the country of origin of solar equipment, there is need to have these product retested here in Zambia to ensure that the quality is not compromised. This will require the setting up of a testing facility to cross check stated specifications.
- There is need to establish a technical standards committee that will determine the compliance of quality standards for SHS and SMG. Inspectors for this committee should carry out physical verification of installed systems to enforce the regulations and standards.

- The lack of enforcement of technical standards led to dissatisfaction caused by power system performance failures which led to people not believing that solar PV systems is a workable technology.
- To ensure sustainability of the technology in the country, there is need to train people in solar technology.
- Since heating appliances are not allowed on solar systems, the traditional way of heating and cooking has still continued that is the use of fire wood and charcoal. This increases the rate of deforestation.

4.6.2 Merits

- Solar mini grids and solar home systems provide electricity solutions to areas which cannot be connected to the national grid.
- Solar mini grids and solar home systems produce clean energy or electricity that does not pollute the environment.
- They have a low maintenance cost
- Although the initial capital invest is high, the long term benefits are low i.e. Net present value is low.
- In order to reduce deforestation, hybrid systems can be encouraged by using solar and biogas where resources for biogas are readily available like in Sinda village.

Chapter 5: Discussion

5.0 Discussion

The current scenario in the project areas is that both the SMG's are in operational with 85.19% of respondents connected in Sinda and 86.49% of respondents connected in Mpanta. In Sinda, 14.81% and in Mpanta, 13.51% households are using solar home system. The SMG is mostly connected to by females who represent 51.9% while 33.3% is by males in Sinda village while 7.4% for both genders use SHS. In Mpanta 43.2% connected customers are females while 37.8% are males and only 8.1% males use SHS with 5.4% females.

5.1 Comparison of Sinda SMG and Mpanta SMG Operations

The Sinda SMG can be singled out as the one which is operating very effectively, this is due to less operational problems experienced than in Mpanta. Therefore customers are generally satisfied with the power being supplied by the SMG and it is in continuous supply for twenty four hours per day. Another reason of exception performance is that the type of load which is allowed is specific, for instance only 5 W lighting bulbs are allowed, the recommended fridges are energy efficient fridges, the television sets power rating should not exceed 100 W and Hi-fi stereo power ratings should not exceed 80 W. The grid supply is also equipped with a sensing mechanism which trips off power whenever a heating appliance is connected.

The only source of complaint is that regardless of the usage by the customers, their billing is the same whether using or not using the power as the meters installed charge per day.

In Mpanta, apparently the supply is at 50% capacity since one of the inverters is not in operational. A schedule has been drawn up to alternate the supply to the other supply line which is not serviced by the damaged inverter. The power is available for 14 hours per day. The load is similar to that found in Sinda but the only difference is that the LED bulbs which are used are 3 W and15 W CFL bulbs, however compact fluorescent lamps have to be certified by the technician to ensure that they conform to required wattage. The usage of ordinary fridges and energy efficient fridges is allowed on the grid. A five ampere circuit break or load limiter is installed in each house to prevent the usage of heating appliances on the grid. The billing is done according to the number of rooms for residential and commercial buildings.

Regardless of the challenges which are being faced, the community is happy that they have a source of electricity in their area.

5.2 Comparison of SMG's and SHS in the Project Areas

The two solar mini-grids visited where 25 kW for Sinda village and a 60 kW in Mpanta village. In this research the range of SHS which was considered was 500 W, this being able to power television set, Hi-fi stereo, fridge, lighting bulbs etc.

At the time of my visit both SMG's where generating power from solar arrays which feed the DC power to the power houses, where batteries, inverters, and charge controllers where housed. The DC power was being feed to the batteries through charge controllers. The DC power produced is stored in batteries and supplied to the inverters for conversion purposes from DC to AC power. The AC power is then supplied to the communities through a local grid network. This power is paid for depending on the tariff whether fixed or prepaid. Maintenance costs are covered by the SMG operators.

In case of SHS basically an individual customizes his design according the amount of appliances which he wishes to use. The system generates enough power for an individual and has a sense of ownership. The power generated is not paid for at any cost and maintenance costs are incurred by the individual. The SHS systems are more reliable in homes of elderly people due to the fact that loads are rarely altered unlike in younger people's households who tend to overload their systems. This clearly shows that younger people like to use a lot of appliances. This situation is also common in younger customers using SMG's power who tend to connected restricted appliances to grid network.

5.3 Comments on Economic Activities in Project Areas

In both villages they have very little economic activities which can allow sustaining the solar mini grids. In the case of Sinda 53.57% of the respondents earn an average annual income of below K6000 (US$ 580.91) meaning that for a customer to be continuously connected to the grid for the whole year he needs K1800 (US$174.22) annually. Therefore for families with a lot of responsibilities this amount is quite colossal, considering that, the need to be connected to the grid becomes a luxury since they have to send children to school, spend some money on health and food.

Similarly in Mpanta the 32.35% of the respondents are fishermen and earn an annual income below K6000 (US$ 580.91) as well. Their core business is fishing and it is a periodic business meaning that in December to March there is a fish ban enforced by government which reduces earnings. Other attributes also affect their earning such as the outbreak of water borne diseases also affect their businesses for example when there was a cholera outbreak in January 2018, the fish ban was extended to April meaning that there was loss of earning by the fishermen.

In order to sustain the power plant in Mpanta the least a customer should pay is K247.30 (at a rate of US $1=K10) per month as calculated from the LCOE in the appendix A1, implying that the amount of energy being consumed is 50 kWh/month.

But with the kind of tariffs that are paid it is very difficult to sustain this mini-grid due to high cost of spare parts e.g. the replacement of the faulty 15 KVA inverter cannot be offset by the revenue collected monthly.

In order to sustain these plants customers should be charged according to their energy usage. This is because certain customers are subsidizing their fellow customers. A true reflection of the energy usage system should be put in place such as installing of prepaid meters which will be billing per kWh usage of energy. Likewise management in Sinda should install prepaid meters that are billing per kWh of energy usage than the fixed day billing and in Mpanta they also need to install prepaid meters for their customers.

On the other hand, if someone would like to own a SHS which is able to connect a number of appliances, the investment cost is over K3630 (US $ 302) as shown in appendix A3 table 6. This is too much for the people in this areas looking at their annual earnings. The only way the systems can be made affordable to the communities is by allowing people to buy the systems on hire purchase and probably introducing subsidies on the systems in these areas. However the cheapest SHS is for lighting only, this system is affordable at a cost of K850 (US $70) as shown in appendix A3 table 6.

Chapter 6: Conclusion and Recommendations

6.0 Conclusion and Recommendations

The research as was aimed at assessing the operation and impacts of SMG and SHS in rural Zambia, and this was mainly focused in Sinda and Mpanta villages since these two villages have solar mini grids already in existence. The study has highlighted that SMG's and SHS are important technologies which provide a source of electricity in rural areas that are off grid.

6.1 Conclusion

The assessment involved assessing the income sources, cost of electricity, stating the investment cost and the load assessments in project areas. Determined how many respondents belonged to the different income groups, what appliances were connected and the social-economic aspects prevailing in the project areas.

It was found that in Sinda village the majority of the respondents earning below K 6000/annum were represented by 53.8%. Out of the 53.8%, 32.1% were females and 21.4% males. The scenario in Mpanta village is equally the same as in Sinda. The incomes earners of below K6000 are in majority at 32.35% comprising of 20.6% females and 11.8% males.

Both villages have very little economic activities which can allow sustaining these solar mini grids. In case of Sinda, the respondents consisted mainly of farmers who represented 78.5% as the major income activity. Out of the 78.5% of farmers, 46.4% are females and 32.1% males engaged in farming activities. Besides farming 7.14% are involved in business, 10.71% in farming and business with 3.57% in other economic activities. From these economic activities the majority of the population earns an average annual income of below K6000 with 32.1% being females and 21.4% males respectively. The appliances which are mostly connected to SMG/SHS are TV sets, fridges, decoders, Hi-Fi stereo and lighting bulbs. The highest users of these appliances are female representing 14.8% and 7.4% men and also from different combinations of appliances. The cost of electricity in Sinda is charged at K5/day. To be continuously connected to the SMG, a customer needs to spend K1800 annually. Therefore for families with more responsibilities, being connected to the SMG becomes a luxury as compared to sending children to schools, providing health care and food.

While in Mpanta village the majority of the respondents are fishermen. Fishing represents 38.24% out of which 26.5% are male and 11.8% females whilst those in employment are at 29.41%, farming represents 14.715%, business at 11.76% and other economic activities at 5.88%. The minimum average annual income is below K6000 out of which 20.6% rare female and 11.8% males, and the maximum is above K60000 represented by 11.8% for both genders respectively. The majority of the populations are those earning below K6000 per annum and most of the customers are in the lower bracket paying a fixed charge of K30-K35 up to the middle bracket of K60. Management feels that the tariff is not sustainable in order to cover for the O&M of the solar mini grid and hence there is need to introduce a cost effective tariff. The affordability of electricity is essentially not bad to the customers, considering that government has already subsidized the electricity tariffs.

The costs of investments where determined from the literature available. This helped to determine the cost of O&M by considering a 10% discount rate on the initial investment costs of the solar mini grids. In case of Sinda SMG the investment cost was US $13,300 therefore the O&M was calculated to be US $1,330. The Mpanta SMG investment cost is documented to be US $1,300,000 therefore the O&M cost at 10% discount rate is US

$13,000. For effective operations of the SMG's both routine maintenance and schedule maintenance are conducted.

In terms of solar home systems, a system designs was done for one system being used for lighting only and the other connected with a few appliances. The cost of equipment was determined from the prevailing markets prices of solar equipment suppliers in Lusaka in 2018. It was calculated that for a 170Wp solar system an initial capital investment of K 3630 is needed to buy two 150Wp solar panels, two 150Ah batteries, a 250W inverter and a 30A charge controller.

In terms of the regulatory framework governing the SMG and SHS are the energy regulation act cap 436, the electricity act cap 433 and the licensing regulation statutory instrument No. 2 of 1998. The Zambian standards of solar mini grids and solar home systems are guided by the ZS 403 which looks at the battery system in the PV systems, specifying the minimum requirements for batteries such as the DoD. The ZS404 standard discusses the charge regulators for the PV systems using lead acid batteries and specifying their requirement for charge regulation fitted on all battery based PV systems. The ZS405 standards look at the PV system design and installation code of practice. It provides for the design and installation of PV energy systems in domestic homes, schools, offices and industrial buildings.

The limitations and merits of these systems were equally discussed. A number of limitation discussed are that, SMG are more beneficial to community development whilst SHS benefit individuals. In solar PV systems, batteries are the weakest link due to a short life span approximately not exceeding five years. Since most of these PV system installed country wide are donor funded, money is not set aside for maintenance and after a few years of operation systems become nonfunctional.

Since our rural areas have low income levels, tariffs have to be subsidized to make them affordable. Retesting of solar PV equipment has to be enforced to insure quality products are on the Zambian market.

Some of the merits of SMG and SHS are that they provide electricity to off grid areas, and the energy produced is clean and does not pollute the environment. They have low maintenance costs and usually their initial capital investment is high but the long term benefits are low. They can reduce the issue of deforestation if hybrid systems are encouraged such as using solar and biogas.

In conclusion solar mini grids and solar home systems are very beneficial sources of electricity for rural areas in the sense that they bring about development. If one is to choose which type of the technology is more viable, I would say solar mini grids are more effective since they cater for a larger population than solar home systems which are individually based. On the other hand SHS are advantageous to an individual who chooses to design the system to their specific energy requirements.

By analyzing the income capacities of households in these project areas, probably 53.5% earning below K6000 per annum in Sinda village and 32% in Mpanta village, cannot be able to afford a properly designed system which can draw a load of over 170W per day and costing K3405. However for those wishing to use a SHS for lighting only, the systems are affordable. In view of this it can only be recommended that SMG are a way to go to spear head development in rural areas.

6.2 Recommendations

Since the project areas are of low economic activities, SMG power can to be utilized for businesses to increasing the household incomes. This in turn will allow for people to be able to afford the electricity being provided by the solar mini grids. If people are able to afford the power, then the income base of the companies running the SMG's will increase thereby ensuring sustainability of the technology.

By again looking at the prevailing income levels in these areas, on average the population in these villages are not capable of making an investment on SHS which can connect several appliances apart from lighting only. The cost of investment is a challenge to people who would like to own such a SHS, for this reason government and solar energy companies should come up with purchasing models which can enable people acquire these systems through loans or hire purchase. However since being connected to the SMG is advantageous but in the long run it is quite costly to a households. It can be recommended that affordable/subsidized tariffs are implemented.

The challenge which mini grid operators face is the cost of spare parts which have to be purchased from abroad in case of faulty equipment, since most of the solar equipment is not manufactured locally. Overall the cost of O&M for both the SMG and SHS is minimal, apart from problems arising from batteries being the weakest link of the PV systems which need frequently replacement, say within a period of three to five years.

Regardless of the cost, SMG is advantageous over the SHS because clients need not worry over the O&M cost which are catered for by the solar mini grid operators whilst with a SHS an individual needs to bear the costs. The availability of spare parts should be readily available locally for those who use SHS. Nevertheless the overall cost of O&M for both the SMG and SHS are minimal.

In order to meet the quality of the specified standard, the Zambia Bureau of Standards and ERB should enforce the law to make sure that the quality of PV products which are available on the market are of high quality and comply to the prevailing standards. This can be done by strengthening the prevailing technical standards, setting up of a PV solar equipment test center, up scaling trainings in solar technology in universities and colleges.

In PV solar systems the major setback is usually the battery storage failures. This can be overcome by encouraging research and development on locally manufacturing batteries with improved efficiency.

- Currently the regulatory and standards of solar PV equipment are under review, however the legislative framework of the energy regulation Act, Cap 436, the electricity Act, Cap 433 and the energy licensing regulation of 1998 are still in effect. The main specific standards which apply in PV technology in Zambia are ZS 403, ZS 404 and ZS 405. The solar PV industry can be strengthened if the institutions regulatory frameworks are strengthened. This can be done by strengthening the prevailing technical standards, setting up of a PV solar equipment test center, providing research on batteries with longer life span and up scaling trainings in solar technology in universities and colleges.

In conclusion SMG and SHS are an effective alternative of providing electricity that can light up rural areas where the national grid electricity is a challenge. In both the areas, people are happy with the power that they receive from these SMG and SHS. Those that are not within the catchment of the 1.5km radius of the grids wish that there can be an expansion to the grid to cater for them or provisions were they can be helped to acquire solar home systems.

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Appendix

Appendix A1: The calculated Levelised Cost of Energy (LCOE) for Sinda Village and Mpanta Village;

Sinda Village

The levelised cost of energy for Sinda village is determined by capital investment cost, the operation and maintenance costs with the overheads are assumed at 10% of the investment costs. This calculation was done to help to compare with the prevailing electricity charge of K5/day.

$$\text{LCOE} = \frac{\text{Capital Investment Cost} + \text{O\&M} + \text{Overhead}}{\text{Plant Life} \times \text{CF} \times 8760\text{hours} \times \text{Plant Capacity}}$$

$$\text{LCOE} = \frac{\text{US }\$133{,}700 + \text{US }\$13{,}370 + \text{US }\$13{,}370}{30 \times 0.2 \times 8760\text{hours} \times 30\text{kW}}$$

$$= \frac{\text{US }\$160{,}440}{1576800\text{kWh}}$$

$$= \mathbf{0.102\ US}\ \$/\mathbf{kWh}$$

Mpanta Village

The levelised cost of energy for Sinda village is determined by capital investment cost, the operation and maintenance costs with the overheads are assumed at 10% of the investment costs. This was done to help compare with the prevailing electricity charges.

$$\text{LCOE} = \frac{\text{Capital Investment Cost} + \text{O\&}M + Overhead}{\text{Plant Life} \times \text{CF} \times 8760\text{hours} \times \text{Plant Capacity}}$$

$$\text{LCOE} = \frac{\text{US }\$1{,}300{,}000 + \text{US }\$130{,}000 + \text{US }\$\ 130{,}000}{30 \times 0.2 \times 8760\text{hours} \times 60\text{kW}}$$

$$= \frac{\text{US }\$1{,}560{,}000}{2628000\text{kWh}}$$

$$= \mathbf{0.4946\ US}\ \$/\mathbf{kWh}$$

Appendix A2: Technical Design of Solar Home System (SHS) for using Lighting Bulbs Only

Table 2: Daily solar radiation values for Petauke

Month	kWh/m2/d
January	5.37
February	5.48
March	5.56
April	5.42
May	5.21
June	4.84
July	4.07
August	5.78
September	6.61
October	6.74
November	6.25
December	5.35
Annual Average	5.64

Retscreen Daily Radiation Values for Petauke, (Source www.Retscreen.com, accessed 23.08.2018)

Load Assessment

Table 3: Daily Energy Requirement

Appliance	Quantity	Power Rating Load (W)	Time of Usage (Hours)	Energy (Wh)
Lighting Bulbs	4	5	6	120
	Totals	20		120

Considering the designing month to be July with 4.07kWh/m^2/day of insolation. The watt peak of solar modules will be determined by dividing the total energy demand by the solar insolation of the design month.

$$\textbf{Module Watt peak Size} = \frac{\text{Total Daily Energy Demand} \times 1.3(\text{Energy lost in the System})}{\text{Value of Insolation for Design Month}}$$

$$= \frac{120\text{Wh} \times 1.3}{4.07} = \mathbf{38.33Wp}$$

Choosing 50Wp solar module size, the number of module needed is;

$$\textbf{Number of Modules} = \frac{\text{Module Watt} - \text{peak Size}}{\text{Module Size}}$$

$$\frac{38.33}{50} = 0.766 \approx \mathbf{1\ Module}$$

Estimating the Battery Capacity (Ah)

Battery efficiency=0.85

Depth of Discharge (DoD)=0.6

System Voltage = 12V

Days of Autonomy= 2

$$\textbf{Battery Bank Capacity (Ah)} = \frac{\text{Total Daily Energy Demand} \times \text{Days of Autonomy}}{(0.85 \times 0.6 \times \text{System Voltage})}$$

$$= \frac{120 \times 2}{0.85 \times 0.6 \times 24} = \mathbf{39.23Ah}$$

Choosing a 50Ah capacity and 12V battery, the number of Batteries required is;

The number of batteries in series;

$$\textbf{Number of Batteries in Series} = \frac{\text{System Voltage (V)}}{\text{Battery Voltage(V)}}$$

$$= \frac{12}{12} = \mathbf{1}$$

The number of batteries in parallel;

$$\textbf{Number of Batteries in Parallel} = \frac{\text{Battery Bank Capacity}}{\text{Battery Capacity}}$$

$$\frac{39.23\text{Ah}}{50\text{Ah}} = 0.785 \approx \textbf{1 Batteries}$$

Choosing the size of the **Solar Charge Controller**;

$$\textbf{Required solar charger current} = 1.2(\text{Safety factor}) \times \frac{\text{Moduele Watt Peak Size}}{\text{Battery Bank Voltage}}$$

$$= 1.2 \times \frac{\text{Number of Modules} \times \text{Module size}}{\text{Battery Bank Voltage}}$$

$$= 1.2 \times \frac{1 \times 50}{12} = \mathbf{5\ A}$$

Choosing the **Inverter Size**;

Taking the inverter to be 150% of the Load

$$\text{Inverter (W)} > 1.5 \times Load\ (W)$$

$$= 1.5 \times 20 = \mathbf{30\ W}$$

Appendix A3: Technical Design of SHS for Lighting bulbs and Appliances

Table 4: Daily solar radiation for Samfya

Month	kWh/m²/d
January	5.03
February	5.12
March	5.43
April	5.66
May	5.80
June	5.71
July	5.91
August	6.46
September	6.76
October	6.57
November	5.92
December	5.63
Annual Average	5.83

Retscreen Daily Radiation Values for Samfya, (Source www.Retscreen.com, accessed 23.08.2018)

Load Assessment

Table 5: Daily Energy Requirement

Appliance	Quantity	Power Rating (W)	Time of Usage (Hours)	Energy (Wh)
Television Set	1	80	6	480
Hi-Fi Stereo	1	50	6	300
Decoder	1	15	6	90
Lighting Bulbs	4	5	6	120
	Totals	170		990

Taking the designing month to be January at 5.03 kWh/m^2/day of insolation. The watt peak of solar modules will be determined by dividing the total energy demand by the solar insolation of the design month.

$$\textbf{Module Watt peak Size} = \frac{\text{Total Daily Energy Demand} \times 1.3(\text{Energy lost in the System})}{\text{Value of Insolation for Design Month}}$$

$$= \frac{990\text{Wh} \times 1.3}{5.03} = \mathbf{255.86Wp}$$

Choosing 150 Wp solar module size, the number of module needed is;

$$\textbf{Number of Modules} = \frac{\text{Module Wattpeak Size}}{\text{Module Size}}$$

$$\frac{255.86}{150} = 1.7 \approx \mathbf{2\ Modules}$$

Estimating the Battery Capacity (Ah)

Battery efficiency=0.85

Depth of Discharge (DoD)=0.6

System Voltage = 12V

Days of Autonomy= 2

$$\textbf{Battery Bank Capacity }(\mathbf{Ah}) = \frac{\text{Total Daily Energy Demand} \times \text{Days of Autonomy}}{(0.85 \times 0.6 \times \text{System Voltage})}$$

$$= \frac{990 \times 2}{0.85 \times 0.6 \times 12} = \mathbf{323.53Ah}$$

Choosing a150Ah capacity and 12V battery, the number of Batteries required is;

The number of batteries in series;

$$\textbf{Number of Batteries in Series} = \frac{\text{System Voltage (V)}}{\text{Battery Voltage(V)}}$$

$$= \frac{12}{12} = \mathbf{1}$$

The number of batteries in parallel;

$$\textbf{Number of Batteries in Parallel} = \frac{\text{Battery Bank Capacity}}{\text{Battery Capacity}}$$

$$\frac{323.53\text{Ah}}{150\text{Ah}} = 2.1 \approx \mathbf{2\ Batteries}$$

Choosing the size of the **Solar Charge Controller**;

$$\textbf{Required solar charger current} = 1.2(\text{Safety factor}) \times \frac{\text{Moduele Watt Peak Size}}{\text{Battery Bank Voltage}}$$

$$= 1.2 \times \frac{\text{Number of Modules} \times \text{Module size}}{\text{Battery Bank Voltage}}$$

$$= 1.2 \times \frac{2 \times 150}{12} = \mathbf{30\ A}$$

Choosing the **Inverter Size**;

Taking the inverter to be 150% of the Load

$$\text{Inverter (W)} > 1.5 \times Load\ (W)$$

$$= 1.5 \times 150 = \mathbf{225\ W}$$

Table 6: Cost of solar equipment in Lusaka, October 2018

	Cost for Lighting and Appliances			
No.	**Solar Equipment**	**Quantity**	**Cost (K)**	**Amount (K)**
i.	Solar Modules (150 Wp)	2	540.00	1,080=00
ii.	Solar Batteries (150 Ah)	2	1,075.00	2150=00
ii.	Inverter (250W)	1	250.00	250=00
iv.	Charge Controller (30A)	1	150.00	150=00
			Total Sum (K)	**3630=00**
	Cost for Lighting Only			
i.	Solar Module (50Wp)	1	250	250
ii.	Solar Battery (50Ah)	1	400	400
iii.	Inverter (30W)	1	150	150
iv.	Charge Controller (5A)	1	50	50
			Total Sum (K)	**850**

Appendix A4: Frequency Tables of Sinda Village

Table 7: Gender representation in Sinda village

	Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	12	42.9	42.9	42.9
	Female	16	57.1	57.1	100.0
	Total	28	100.0	100.0	

Table 8: Source of income in Sinda village

	Income Sources	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Business	2	7.1	7.1	7.1
	Farming	22	78.6	78.6	85.7
	Other	1	3.6	3.6	89.3
	Business, Farming	3	10.7	10.7	100.0
	Total	28	100.0	100.0	

Table 9: Representation of Income Sources by Gender in Sinda Village

Income Sources	Male(s) Percent(%)	Female Percent (%)
Business	3.6	3.6
Farming	32.1	46.4
Business, Farming	3.6	7.1
Other	0	3.6

Table 10: Annual income in Sinda village

	Income Levels (K)	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Below 6000	15	53.6	53.6	53.6
	Between 6000-15000	7	25.0	25.0	78.6
	Between 15000-30000	6	21.4	21.4	100.0
	Total	28	100.0	100.0	

Table 11: Representation of Average annual Income in Sinda Village

	Male(s) Percent (%)	**Female Percent (%)**
Below K6000	21.4	32.1
Between K6000-K15000	14.3	10.7
Between K15000-K30000	14.3	7.1

Table 12: Combination of appliances connected to SMG and SHS in Sinda village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Lighting Bulbs	4	14.8	14.8	14.8
	Lighting Bulbs &Televsion Set	6	22.2	22.2	37.0
	Lighting Bulbs & Hi-Fi Stereo	3	11.1	11.1	48.1
	Lighting Bulbs, Television Set, Hi-Fi Stereo	3	11.1	11.1	59.3
	Lighting Bulbs, Television Set, Hi-Fi Stereot & Decoder	6	22.2	22.2	81.5
	Ligthing Bulbs,Television Set, Hi-Fi Stereo, Decoder	2	7.4	7.4	88.9
	Lighting Bulbs, Television Set, Hi-Fi Stereo, Decoder & Fridge	3	11.1	11.1	100.0
	Total	27	100.0	100.0	

Table 13: Combination of appliances connected to the SMG/SHS by gender

	Male(s) Percent(%)	Female Percent (%)
Lighting Bulbs	3.7	11.1
Lighting Bulbs & TV Set	11.1	11.1
Lighting Bulbs Hi-fi Stereo	7.4	3.7
Lighting Bulbs TV Set, Hi-fi Stereo	11.1	11.1
Lighting Bulbs, TV Set, Hifi & Decoder	7.4	14.8
Lighting Bulbs, TV Set and Decoder	3.7	3.7
Lighting Bulbs, TV Set, Hi-fi Stereo, Decoder & Fridge	7.4	3.7

Table 14: The Rated appliance Wattages in Sinda village households

	Appliances	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fridges (80W-100W)	7	11.3	11.3	11.3
	Television Sets (80W-!00W)	15	24.2	24.2	35.5
	Decoders (15W)	16	25.8	25.8	61.3
	Hi-Fi Stereo (80W-100W)	24	38.7	38.7	100.0
	Total	62	100.0	100.0	

Table 15: Types of business conducted in Sinda village

	Business	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mobile Phone Charging	1	3.6	3.6	3.6
	Home Shop	5	17.9	17.9	21.4
	Barbershop, Mobile Phone Charging	1	3.6	3.6	25.0
	Bar	1	3.6	3.6	28.6
	Non	18	64.3	64.3	92.9
	Pay TV Watching	1	3.6	3.6	96.4
	Taloring	1	3.6	3.6	100.0
	Total	28	100.0	100.0	

Table 16: SMG versus SHS usage in Sinda village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	SMG	23	85.2	85.2	85.2
	SHS	4	14.8	14.8	100.0
	Total	27	100.0	100.0	

Table 17: Gender representation of SMG and SHS usage in Sinda village

	SMG	SHS
Male(s) Percent(%)	33.3	7.4
Female Percent (%)	51.9	7.4

Appendix A5: Frequency Tables for Mpanta Village

Table 18: Gender representation in Mpanta village

	Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	14	41.2	41.2	41.2
	Female	20	58.8	58.8	100.0
	Total	34	100.0	100.0	

Table 19: Level of education in Mpanta village

	Education	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	University	2	5.9	5.9	5.9
	College	8	23.5	23.5	29.4
	Secondary School	10	29.4	29.4	58.8
	Primary	12	35.3	35.3	94.1
	No Education	2	5.9	5.9	100.0
	Total	34	100.0	100.0	

Table 20: Sources of income in Mpanta village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Business	4	11.8	11.8	11.8
	Farming	5	14.7	14.7	26.5
	Fishing	13	38.2	38.2	64.7
	Employment	10	29.4	29.4	94.1
	Other	2	5.9	5.9	100.0
	Total	34	100.0	100.0	

Table 21: Representation of income sources by gender

	Male(s) Percent (%)	Female Percent (%)
Business	5.9	5.9
Farming	8.8	5.9
Fishing	26.5	11.8
Employment	14.7	14.7
Other	2.9	2.9

Table 22: Average annual income in Mpanta village

	Average Annual Income (K)	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Below 6000	11	32.4	32.4	32.4
	Between 6000-15000	8	23.5	23.5	55.9
	Between 15000-30000	5	14.7	14.7	70.6
	Between 30000-600000	4	11.8	11.8	82.4
	Above 60000	6	17.6	17.6	100.0
	Total	34	100.0	100.0	

Table 23: Representation of average annual income by gender in Mpanta village

	Male(s) Percent (%)	Female Percent (%)
Below K6000	11.8	20.6
Between K6000-K15000	14.7	8.8
Between K15000-K30000	8.8	5.9
Between K30000- K60000	8.8	2.9
Above K60000	11.8	11.8

Table 24: Fixed charges of Mpanta village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	K30 per Month	7	20.6	20.6	20.6
	K35 per Month	5	14.7	14.7	35.3
	K50 per Month	3	8.8	8.8	44.1
	K60 per Month	12	35.3	35.3	79.4
	K65 per Month	1	2.9	2.9	82.4
	K70 per Month	3	8.8	8.8	91.2
	K100 per Month	1	2.9	2.9	94.1
	Free	2	5.9	5.9	100.0
	Total	34	100.0	100.0	

Table 25: Gender representation of cost of tariff

	Male(s) Percent (%)	Female Percent (%)
K30 per Month	8.8	11.8
K35 per Month	2.9	14.7
K50 per Month	5.9	2.9
K60 per month	14.7	20.6
K65 per Month	2.9	0
K70 per Month	5.9	2.9
K100 per Month	2.9	0
Free	5.9	0

Table 26: Combination of appliances connected to SMG/SHS in Mpanta village

	Combinations of Appliances	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Lighting Bulbs	6	5.2	16.7	16.7
	Lighting Bulbs & TV	9	7.8	25.0	41.7
	Lighting Bulbs & Hi-Fi Stereo	5	4.3	13.9	55.6
	Lighting Bulbs & Fridge	1	.9	2.8	58.3
	Lighting, Bulbs, TV & Hi-Fi Stereo	6	5.2	16.7	75.0
	Lighting Bulbs, TV & Decoder	2	1.7	5.6	80.6
	Lighting Bulbs, TV, Hi-Fi Stereo, Decoder	4	3.5	11.1	91.7
	Lighting Bulb, TV, Hi-Fi Stereo, Decoder & Fridge	3	2.6	8.3	100.0
	Total	36	100.0	100.0	

Table 27: Combination of appliances usage by gender

	Male(s) Percent (%)	Female Percent (%)
Lighting Bulbs	5.6	11.8
TV set, HI-Fi Stereo, Fridge, Lighting Bulbs, Decoder	5.6	2.8
TV set, HI-Fi stereo, Lighting Bulbs	8.3	8.3
Hi-Fi stereo, Lighting Bulbs	5.6	8.3
TV set, Lighting Bulbs, Decoder	2.8	2.8
TV, Lighting Bulbs	13.9	11.1

Table 28: Available appliance wattages in Mpanta village

	Appliance Wattages	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fridge (80W-100W)	3	6.2	6.2	6.2
	Hi-Fi Stereo (60W-80)	6	12.5	12.5	18.8
	Television Sets (80W-100W)	8	16.7	16.7	35.4
	Decoders (15W)	5	10.4	10.4	45.8
	LED Bulbs (3W)	12	25.0	25.0	70.8
	LED Bulbs (5W)	8	16.7	16.7	87.5
	CFL Lamps(15W)	6	12.5	12.5	100.0
	Total	48	100.0	100.0	

Table 29: Type of business conducted in Mpanta village

	Business Conducted	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Barbershop	1	6.2	6.2	6.2
	Home shops	2	12.5	12.5	18.8
	Barbershop and Mobile Phone Charging	1	6.2	6.2	25.0
	Shops	6	37.5	37.5	62.5
	Harbour Deports	4	25.0	25.0	87.5
	Bars	2	12.5	12.5	100.0
	Total	16	100.0	100.0	

Table 30: SMG versus SHS usage in Mpanta village

Usage		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	SMG	32	86.5	86.5	86.5
	SHS	5	13.5	13.5	100.0
	Total	37	100.0	100.0	

Table 31: Gender representation of SMG Vs SHS usage in Mpanta village

	SMG	SHS
Male(s) Percent (%)	37.8	8.1
Female Percent (%)	43.2	5.4

The University of Zambia

School of Engineering

Department of Mechanical Engineering

Dear Respondent,

This research is conducted by Francis Musonda, a final year student in Renewable Energy Engineering in the Department of Mechanical Engineering at the University of Zambia. The purpose of this research is to collect data on the assessment of solar mini grids and solar home systems in rural Zambia.

The data will be used sorely for academic purposes and treated with the confidentiality deserved.

You are requested to fill in the questionnaire as accurately as possible.

Thanking you in advance for your co-operation.

Yours sincerely,

UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH GRADUATE STUDIES

QUESTIONNAIRE FOR SOLAR MINI GRID MANAGERS

ON

The Assessment of Solar Home Systems and Solar Mini Grids in Rural Zambia

(Please Tick (√) or explain as appropriate)

Note: The information provided is strictly for academic purposes and will be treated with high confidentiality.

Part One: Solar Mini Grid Performance Assessment

1.	How long has the solar mini grid been in existence? 1. One year ☐ 2. Two years ☐ 3.Three years ☐ 4. Four years ☐ 5. Five years ☐ 6. Other, please specify…………………..
2.	Who installed the solar mini grid? 1. Local Contractor ☐ 2. Foreign Contractor ☐ 3.Goverment ☐ 4. Other, please specify………………………………………………………
3.	How has the grid supply been performing? 1. Excellent ☐ 2. Very good ☐ 3. Good ☐ 4. Fair ☐ 5. Not working ☐
4.	Did the Zambia bureau of standards test the components? 1. Yes ☐ 2. No ☐
5.	Do you have a warranty for your solar mini grid components? 1. Yes ☐ 2. No ☐

6.	How often do you test your components? Please explain………………………………………………………… ……………………………………………………………………………………… ……………………………………………………………………………………… ……………………………………………………………………………………… ……………
7.	In case of faulty equipment, are spares readily available in Zambia? 1. Yes ☐ 2. No ☐
8.	Did you undertake any form of solar photovoltaic training? 1. Yes ☐ 2. No
9.	If **No in question 14**, specify the reason? ……………………………………………………………………………………… …………………………………………….. ……………………………………………………………………………………… …………………………………………….
10.	What is the solar mini grid plant size and how many solar panels are they? Please specify ……………………………………………………………………………………… ……………………………………………. ……………………………………………………………………………………… …………………………………………….
11.	How is the solar panel configuration, please specify?.. ……………………………………………………………………………………… ……………………………………………. ……………………………………………………………………………………… …………………………………………….
12.	What is the size / capacity of your battery bank and how many are they?........................

	……………………………………………………………………………………………… …………………………………………….. ……………………………………………………………………………………………… ……………………………………………..
13.	How is the battery configuration? please specify……………………………………………………………………… ……………………………………………………………………………………………… …………………………………………………….. ……………………………………………………………………………………………… ……………………………………………………..
14.	What is the size of the inverters, how many are they and how are they connected?................... ……………………………………………………………………………………………… ……………………………………………………..
15.	What is the rating of the charge controllers and how are they connected? ..………..................... ……………………………………………………………………………………………… ………………………………………………………
16.	How many customers are connected to the solar mini grid?.. ……………………………………………………………………………………………… ……………………………………………………… ……………………………………………………………………………………………… ……………………………………………………..
17.	Are they on prepaid meter or fixed tarriff? 1. Prepared Meter ☐ 2. Fixed Tarriff ☐
18.	If the answer to question 23 is **fixed tarriff,** what is the cost per month? 1. K50 ☐ 2. K100 ☐ 3. K150 ☐ 4. K200 ☐ 5. Other, please specify………………………
19.	If they are on **prepaid** meters, what is the cost per kWh?

	1. 0.2 ☐ 2. 0.25 ☐ 3. 0.3 ☐ 4. 0.35 ☐ 5. Other, Specify………………………………………… ……………………………………………………………………………………………… …………………………………………………..
20.	How many times is power switched off for maintenance in a month? 1. Once ☐ 2. Twice ☐ 3. Thrice ☐ 4. Four times ☐ 5. Never ☐
21.	Do you receive complaints from customers during maintenance? 1. Yes ☐ 2. No ☐
22.	How long is the power available in a day? 1. 24h ☐ 2. 18h ☐ 3. 12h ☐ 4. 6h ☐ 5. Other, Please specify……………………………….
23.	How long is the power available during the night? 1. 24h ☐ 2. 18h ☐ 3. 12h ☐ 4. 6h ☐ 5. Other, Please specify……………………………….
24.	Which type of appliance are customers allowed to use?.. ………………………………………………………………………………………………
25.	Are your customers satisafied with your service? 1.Yes ☐ 2. No ☐
26.	If the answer is **No to question 32**, please specify……………………………………………………………………… ……………………………………………………………………………………………… …………………………………………………… ……………………………………………………………………………………………… …………………………………………………..
27.	Are you happy with the overall performance of your solar mini grid? 1. Yes ☐ 2. No ☐
28.	If the answer is **No** in question 32, give reasons and what would you prefer as an alternative source of power supply in your community? Please explain…………………………………………………

	……………………………………………………………………………………………… ………………………………………………………. ……………………………………………………………………………………………… ……………………………………………………….
29.	What challenges have you faced from the time of inception of the solar mini grid? Please explain……………………………………………………………………………………… …………………………………………………….. ……………………………………………………………………………………………… ………………………………………………………….. ……………………………………………………………………………………………… ………………………………………………………….. ……………………………………………………………………………………………… ………………………………………………………….. ……………………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………………………………………………………… ………………..
30.	How has the community received this project from your perception?.. ……………………………………………………………………………………………… ……………………………………………………………………………………………… ………………………………………………………………………………………………. ……………………………………………………………………………………………… ………………………………………………………………………………………………

Part Two : Demographic Information

31.	Name (Optional) : Tel:
32.	Gender 1. Male ☐ 2. Female ☐
33.	Postion:
34.	Marital Status 1.Married ☐ 2.Single ☐ 3.Divorced ☐ 4.Widower ☐ 5.Widow ☐ 6. Separated ☐
35.	Age 1. 18-24yrs ☐ 2. 25-30yrs ☐ 3. 31-35yrs ☐ 4. 36-40yrs ☐ 5. 41-45yrs ☐ 6. 46-50yrs ☐ 7. 51-55yrs ☐ 8. 56-60yrs ☐ 9. Above 60yrs ☐
36.	Which of the following best describes your occupation? 1.Business Person ☐ 2. Civil Servant ☐ 3. Farmer ☐ 4. Fisherman ☐ 5. Other (Please Specify)…………………………………………………
37.	What is your level of education? 1. University ☐ 2. College ☐ 3. Secondary School ☐ 4. Primary School ☐ 5. No Education ☐

Thank You for Responding to the Interview. Your Time is Highly Appreciated

UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH GRADUATE STUDIES

QUESTIONNAIRE FOR SOLAR MINI GRID CONNECTED CUSTOMERS

ON

The Assessment of Solar Home Systems and Solar Mini Grids in Rural Zambia

(Please Tick (√) or explain as appropriate)

Note: The information provided is strictly for academic purposes and will be treated with high confidentiality.

Part One: Demographic Information

1.	Name (Optional) : Tel:
2.	Gender 1. Male ☐ 2. Female ☐
3.	Marital Status 1.Married ☐ 2.Single ☐ 3.Divorced ☐ 4.Widower ☐ 5.Widow ☐ 6. Separated ☐
4.	Age 1. 18-24yrs ☐ 2. 25-30yrs ☐ 3. 31-35yrs ☐ 4. 36-40yrs ☐ 5. 41-45yrs ☐ 6. 46-50yrs ☐ 7. 51-55yrs ☐ 8. 56-60yrs ☐ 9. Above 60yrs ☐
5.	Which of the following best describes your occupation? 1.Business Person ☐ 2. Civil Servant ☐ 3. Farmer ☐ 4. Fisherman ☐

	5. Other (Please Specify)…………………………………………………..
6.	What is your level of education? 1. University ☐ 2. College ☐ 3. Secondary School ☐ 4. Primary School ☐ 5. No Education ☐

Part Two: Solar Mini Grid Performance Assessment for Customers

7.	How long have you been connected to the solar mini grid? 1. One year ☐ 2. Two years ☐ 3.Three years ☐ 4. Four years ☐ 5. Five years ☐ 6. Other, please specify…………………..
8.	How has the grid supply been performing? 1. Excellent ☐ 2. Very good ☐ 3. Good ☐ 4. Fair ☐ 5. Not working ☐
9.	Who connected you to the electricity supply of the solar mini grid? 1. Solar Technician ☐ 2. Electrician ☐ 3. Self ☐ 4. Friend ☐ 5. Salesman ☐
10.	If the answer to question 9 is 2, 3, 4 and 5. Is the installer trained in solar photovoltaics (PV)? 1. Yes ☐ 2. No ☐
11.	After installation, did they educate you on the usage? 1. Yes ☐ 2. No ☐
12.	Are you on prepaid meter or fixed tarriff? 1. Prepared Meter ☐ 2. Fixed Tarriff ☐
13.	If the answer to **question 12 is fixed tarriff,** what is the cost per month? 1. K50 ☐ 2. K100 ☐ 3. K150 ☐ 5. K200 ☐ 6. Other, please specify………………………

14.	How many units do you use per month? 1. 5kWh ☐ 2. 10kWh ☐ 3. 15kWh ☐ 4. 20kWh ☐ 5. Other, Specify…………………
15.	How many times is power switched off for maintenance in a month? 1. Once ☐ 2. Twice ☐ 3. Thrice ☐ 4. Four times ☐ 5. Five times and over ☐ 6. Never ☐
16.	Do you experience any unnecessary power outages? 1. Yes ☐ 2. No ☐
17.	How long is the power available in a day? 1. 24h ☐ 2. 18h ☐ 3. 12h ☐ 4. 6h ☐ 5. Other, Please specify…………………………
18.	Which type of appliance are you allowed to use? 1. TV sets ☐ 2. Hi-Fi ☐ 3. Lighting Bulbs ☐ 4.Fridges ☐ 5. Heaters ☐
19.	Do you have a solar home system as backup? 1. Yes ☐ 2. No ☐
20.	If **yes**, what is the size of solar panels? 1. 80W ☐ 2. 100W ☐ 3. 150W ☐ 4. 200W ☐ 5. Other, Specify…………………
21.	What is the capacity of your battery? 1. 50Ah ☐ 2. 80Ah ☐ 3. 100Ah ☐ 4. 150Ah ☐ 5. 200Ah ☐ 6. Above 200Ah ☐
22.	What is the size of your inverter? 1. 350W ☐ 2. 450W ☐ 5. 500W ☐ 6.750W ☐ 7. 1000W ☐ 8. If other specify…………………
23.	How long do you use your back up system during the day? 1. One hour ☐ 2. Two hours ☐ 3. Three hours ☐ 4. Four hours ☐ 5. Five hours and above ☐
24.	How long do you use your back up system during the night? 1. One hour ☐ 2. Two hours ☐ 3. Three hours ☐ 4. Four hours ☐

	5. Five and above ☐
25.	Do you experience any problems with solar mini grid supply? 1. Yes ☐ 2. No ☐
26.	How do you compare the two systems, the SHS and SMG? 1. SMG power supply is more reliable ☐ 2. SHS power supply is more reliable ☐ 3. Both are reliable ☐ 4. None of them are reliable ☐
27.	Are you happy with the overall performance of solar mini grid supply? 1. Yes ☐ 2. No ☐
28.	If the answer is **No in question 27**, what would you prefer as an alternative source of power supply in your community? Please explain……………………………………………………………

Part 3: Load Assessment

29.	How many lighting bulbs are connected? 1. One ☐ 2. Two ☐ 3. Three ☐ 4.Four ☐ 5. Five ☐ 6. Six and above ☐
30.	Which type of bulbs do you use? 1. Incandescent ☐ 2. LED ☐ 3. Compact Fluorescent Lamps ☐ 4. Florescent ☐
31.	What is the power rating of your bulbs? 1. 5-10W ☐ 2. 10-15W ☐ 3. 15-20W ☐ 4. Above 20W ☐
32.	Do you own a television set? 1. Yes ☐ 2. No ☐
33.	If yes, what is the power rating of your TV set? 1. 50W ☐ 2. 80W ☐ 3. 100W ☐ 4. 120W ☐ 5.150W ☐ 6. Above 150W ☐
34.	Do you own a fridge?

	1. Yes ☐ 2. No ☐
35.	If yes, what is the power rating of your fridge? 1. 60W-80W ☐ 2. 80W-100W ☐ 3. 100W-120W ☐ 4. 120W-140W ☐ 5. Above 140W ☐
36.	Do you own a Hi-Fi system? 1. Yes ☐ 2. No ☐
37.	If yes, what is the power rating of your Hi-Fi system? 1. 50W ☐ 2. 80W ☐ 3. 100W ☐ 4. 150W ☐ 5. 250W ☐
38.	Do you own a decoder? 1. Yes ☐ 2. No ☐
39.	If yes, what is the power rating of your decoder? 1. 10-15W ☐ 2. 15-20W ☐ 3. 20-25W ☐ 4. 25-30W ☐

Part 4: Socio-Economical and Education

40.	What is your source of income(s)? 1. Business ☐ 2. Farming ☐ 3. Fishing ☐ 4. Employment ☐ 5. Other ☐
41.	What is your average monthly income (K)? 1. Below 500 ☐ 2. 500-1000 ☐ 3. 1000-1500 ☐ 4. 1500-2000 ☐ 5. Above 2000 ☐
42.	What is your average annual income (K)? 1. Below 6000 ☐ 2. 6000-15000 ☐ 3. 15000-30000 ☐ 4. 30000-60000 ☐ 5. Above 60000 ☐
43.	How did pay your connection fee? 1. Paid cash ☐ 2. Paid by installments ☐ 3. Paid by a relative ☐ 4. Other, please specify …………………………………………………………………
44.	How much did it cost (K)?

	1. 100 ☐ 2. 150 ☐ 3. 200 ☐ 4. Other, please specify…………………………………………
45.	Do you use your solar power for business? 1. Yes ☐ 2. No ☐
46.	What type of business? 1. Mobile Phone Charging ☐ 2. Batter Charging ☐ 3. Barbershop ☐ 4. Home Shop Lighting ☐
47.	How many school going children do u have? 1. One ☐ 2. Two ☐ 3. Three ☐ 4. Four ☐ 5.Five 6. Above Five ☐
48.	Do they do their school work at night? 1. Yes ☐ 2. No ☐
49.	What type of lighting do they use? 1. SMG Lighting ☐ 2. Candle ☐ 3. Paraffin Lantern ☐ 4. Solar Lantern ☐
50.	Has the performance of your children improved at school? 1. Yes ☐ 2. No ☐
51.	How do you recommend solar mini grid power? 1. Excellent ☐ 2. Good ☐ 3. Fair ☐ 4. Poor ☐

Thank You for Responding to the Interview. Your Time is Highly Appreciated

UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH GRADUATE STUDIES

QUESTIONNAIRE FOR SOLAR HOME SYSTEM OWNERS

ON

The Assessment of Solar Home Systems and Solar Mini Grids in Rural Zambia

(Please Tick (√) or explain as appropriate)

Note: The information provided is strictly for academic purposes and will be treated with high confidentiality.

Part One: Demographic Information

1.	Name (Optional) : Tel:
2.	Gender; 1. Male ☐ 2. Female ☐
3.	Marital Status 1.Married ☐ 2.Single ☐ 3.Divorced ☐ 4.Widower ☐ 5.Widow ☐ 6. Separated ☐
4.	Age 1. 18-24yrs ☐ 2. 25-30yrs ☐ 3. 31-35yrs ☐ 4. 36-40yrs ☐ 5. 41-45yrs ☐ 6. 46-50yrs ☐ 7. 51-55yrs ☐ 8. 56-60yrs ☐ 9. Above 60yrs ☐
5.	Which of the following best describes your occupation? 1.Business Person ☐ 2. Civil Servant ☐ 3. Farmer ☐ 4. Fisherman ☐ 5. Other (Please Specify)…………………………………………………..
6.	What is your level of education? 1. University ☐ 2. College ☐ 3. Secondary School ☐ 4. Primary School ☐

	5. No Education

Part Two: Solar Home System Performance Assessment

7.	How long have you owned the solar home system? 1. One year 2. Two years 3.Three years 4. Four years 5. Five years 6. Other, please specify…………………..
8.	How has your solar home system been performing? 1. Excellent 2. Very good 3. Good 4. Fair 5. Not working
9.	Who installed your solar home system? 1. Solar Technician 2. Electrician 3. Self 4. Friend 5. Salesman
10.	If the answer to **question 9 is 2, 3, 4 and 5.** Is the installer trained in solar photovoltaics (PV)? 1. Yes 2. No
11.	After installation of your SHS, did you receive any form of training? 1. Yes 2. No
12.	What is the size of your solar home system? 1. 80W 2. 100W 3. 150W 4. 200W 5. Other, Specify………………….
13.	How many times do you clean your solar panel in a month? 1. Once 2. Twice 3. Thrice 4. Four times 5. Five times and over 6. Never
14.	Which orientation/direction do your solar panels face? 1. East 2. West 3. South 4. North
15.	What type of batteries is connected to your SHS? 1. Lead Acid 2. Lithium Ion 3. GEL Lead Acid 4. Absorbed glass Matt(AGM)
16.	What is the size of your battery bank?

	1. 50Ah ☐ 2.80Ah ☐ 3. 100Ah ☐ 4. 150Ah ☐ 5. 200Ah ☐ 6. Above 200Ah ☐
17.	Which type of controller is connect to your SHS? 1. Simple one or two stage Control ☐ 2. Pulse Width Modulated (PWM) ☐ 3. Maximium Power Point Tracker (MPPT) ☐ 4. Non ☐
18.	What type of inverter is connected to your SHS? 1. Pure Sine Wave ☐ 2. Modified square Wave ☐ 3. Square Wave ☐ 4. Non ☐
19.	What is the size of your inverter? 1. 350W ☐ 2. 450W ☐ 5. 500W ☐ 6.750W ☐ 7. 1000W ☐ 8. If other specify………………
20.	How long do you use your system during the day? 1. One hour ☐ 2. Two hours ☐ 3. Three hours ☐ 4. Four hours ☐ 5. Five hours and above ☐
21.	How long do you use your system during the night? 1. One hour ☐ 2. Two hours ☐ 3. Three hours ☐ 4. Four hours ☐ 5. Five and above ☐
22.	Do you experience any problems with your solar system? 1. Yes ☐ 2. No ☐
23.	If **yes**, what type of problems do you experience? 1. System operates for a few hours at night ☐ 2.Batteries are never c☐ged 3. Solar panel produce less current ☐ 4.Charge controllers are always ☐ty
24.	Are spare parts readily available? 1. Yes ☐ 2. No ☐
25.	Are your solar components tested by Zambia Bureau of standards? 1. Yes ☐ 2. No ☐
26.	Do you have a warranty for your solar home system components? 1. Yes ☐ 2. No ☐
27.	How often do you test your solar home system components? Please explain…………………

28.	If no, why don't you test your solar home system components? 1. No testing facility ☐ 2. High testing cost ☐ 3. High cost of transport to testing facility ☐ 4. Other, please specify…………………………………
29.	Are you happy with the overall performance of your solar home system? 2. Yes ☐ 2. No ☐
30.	If the answer is **No in question 29**, would you prefer to connect to a solar mini grid? 1. Yes ☐ 2. No ☐

Part 3: Load Assessment

31.	How many lighting bulbs are connected to the SHS? 1. One ☐ 2. Two ☐ 3. Three ☐ 4.Four ☐ 5. Five ☐ 6. Six and above ☐
32.	Which type of bulbs do you use? 1. Incandescent ☐ 2. LED ☐ 3. Compact Fluorescent Lamps ☐ 4. Florescent ☐
33.	What is the power rating of your bulbs? 1. 5-10W ☐ 2. 10-15W ☐ 3. 15-20W ☐ 4. Above 20W ☐
34.	Do you own a television set? 1. Yes ☐ 2. No ☐
35.	If yes, what is the power rating of your TV set? 1. 50W ☐ 2. 80W ☐ 3. 100W ☐ 4. 120W ☐ 5.150W ☐ 6. Above 150W ☐
36.	Do you own a fridge? 1. Yes ☐ 2. No ☐
37.	If yes, what is the power rating of your fridge? 1. 60W-80W ☐ 2. 80W-100W ☐ 3. 100W-120W ☐ 4. 120W-140W ☐ 5. Above 140W ☐
38.	Do you own a Hi-Fi system?

	1. Yes ☐ 2. No ☐
39.	If yes, what is the power rating of your Hi-Fi system? 1. 50W ☐ 2. 80W ☐ 3. 100W ☐ 4. 150W ☐ 5. 250W ☐
40.	Do you own a decoder? 1. Yes ☐ 2. No ☐
41.	If yes, what is the power rating of your decoder? 1. 10-15W ☐ 2. 15-20W ☐ 3. 20-25W ☐ 4. 25-30W ☐
42.	Are you, connected to the solar mini grid? 1. Yes ☐ 2. No ☐

Part 4: Socio-Economical and Education

43.	What is your source of income(s)? 1. Business ☐ 2. Farming ☐ 3. Fishing ☐ 4. Employment ☐ 5. Other ☐
44.	What is your average monthly income (K)? 1. Below 500 ☐ 2. 500-1000 ☐ 3. 1000-1500 ☐ 4. 1500-2000 ☐ 5. Above 2000 ☐
45.	What is your average annual income (K)? 1. Below 6000 ☐ 2. 6000-15000 ☐ 3. 15000-30000 ☐ 4. 30000-60000 ☐ 5. Abov☐0000 ☐
46.	How did you acquire your solar home system? 1. Bought by cash ☐ 2. Bought by credit ☐ 3. Bought by a relative ☐ 4. Gift ☐
47.	How much did it cost (K) approximately? 1. 1000-4000 ☐ 2. 4000-8000 ☐ 3. 8000-10000 ☐ 4. Above 10000 ☐
48.	Do you use your SHS for business? 1. Yes ☐ 2. No ☐
49.	What type of business?

	1. Mobile Phone Charging ☐ 2. Batter Charging ☐ 3. Barbershop ☐ 4. Home Shop ☐
50.	How many school going children do you have? 1. One ☐ 2.Two ☐ 3.Three ☐ 4. Four ☐ 5.Five ☐ 6. Above Five ☐
51.	Do they do their school work at night? 2. Yes ☐ 2. No ☐
52.	What type of lighting do they use? 1. SHS Lighting ☐ 2. Candle ☐ 3. Paraffin Lantern ☐ 4. Solar Lantern ☐
53.	Has the performance of your children improved at school? 2. Yes ☐ 2. No ☐
54.	How do you differentiate your life before and after the solar home sytem? 1. Better ☐ 2. Worse ☐ 3. Fair ☐ 4. Regretable ☐
55.	How do you recommend solar home system? 1. Excellent ☐ 2. Good ☐ 3. Fair ☐ 4. Poor ☐

Thank You for Responding To the Questionnaire. Your Time Was Highly Appreciated