SOLAR PV POTENTIAL IN RURAL ZIMBABWE

ANALYSING NATURAL AND ECONOMICAL POTENTIAL

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Abstract

Socioeconomic development in Zimbabwe is reduced by the fact that a majority of the households in rural areas has no access to electricity. Households rely for their energy supply on expensive and unsustainable products like paraffin oil and fire wood. The fact that Zimbabwe has an average annual of 8.3 sun hours per day makes the country suitable for solar energy; one solution for this energy shortage could be the development of a solar energy network in rural Zimbabwe. This research examines the economical and natural potential for solar energy to find out whether there are possibilities to develop a sustainable solar energy sector not based on long-term subsidy programs.

Through two different paths, the natural and economic potential of solar energy in rural areas in Zimbabwe is examined. The natural potential of solar energy is derived from sun hours data from the meteorological institute in Zimbabwe using the angstrom analysis. Solar irradiation is calculated into a potential electricity production per square meter. The results are checked with satellite data from the PVGIS program. Two household surveys are conducted to research the economic potential for solar energy. The first survey covers the current energy use of households. The second survey studies willingness to pay for solar products. The economical potential for solar energy is derived by linking WTP and income results to actual market size.

The climate in Zimbabwe is suitable for solar energy with an average electricity potential for solar PV of 359 kWh/m$^{2/}$year. Rural areas in Zimbabwe have a large potential for the development of solar PV market. The majority of the households is capable and willing to pay enough to purchase simple solar products. There is a need for the development of payment schemes to make more advanced solar system affordable for rural households. Furthermore solutions to integrated solar energy into the current energy systems are needed to fully utilize the natural solar PV potential

Acknowledgement

This master thesis study was made possible by the support from SNV Zimbabwe, IVM, ILO Zimbabwe and RENEW IS Academy. I would like to thank my external supervisor Erik Boonstoppel at SNV Zimbabwe for his excellent guidance and advice. I would also like to acknowledge the efforts and commitment from my renewable energy colleagues Gladys, Fungai and Chandi that helped me with advice and support within the stimulating work environment of SNV. Thanks to my supervisors Pieter van Beukerink from IVM and Mark Bokhorst from earth sciences. This research could not have been completed without the help of 10 district staff members from ILO conducting the surveys, thanks for their enthusiasm and persistence.

Preface

This report is written within the RENEW IS academy, this is a five year (2009-2014) research project investigating energy access and development cooperation in Eastern Africa. It is funded by the Dutch Ministry of Foreign Affairs (DGIS) and is a joint collaboration of IVM (Institute for Environmental Studies, VU University Amsterdam), ECN (Energy research Centre of the Netherlands) and the environment, water, climate and energy department of DGIS. Within this program I did an internship with SNV Netherlands Development Organization in Zimbabwe. SNV in partnership with International Labour Organization (ILO) is investing in value chain development for rural solar PV markets. The intervention seeks to reduce the high transaction costs for solar products and their maintenance in rural areas by approximately 70% through establishing local sales, after-sales and maintenance networks. This will be done by fostering business relations between youth in rural localities and solar companies in towns while creating an environment where financing products are available on the market for affordability of the solar systems and products. ILO would like to create meaningful self-employment opportunities for 180 people between 15-35 years of age in 2013. SNV would like to increase access to renewable energy for rural communities in Zimbabwe (SNV & ILO, 2012). Collaboration between SNV and ILO started with this research to investigate whether there is a natural and economical potential for solar PV in rural areas of Zimbabwe. Does it make sense to invest in a training program for the stimulation of a market based solar energy market based on economical and natural factors?

Earth science and economics

This study is done within the master Earth science, specialization earth science and economics. This master aims to work within the tension of earth science and economics. Therefore this study will study both; economical feasibility of solar energy and natural potential of solar irradiation.

Abbreviations

CV(M): Contingent Valuation (Method)

GDP: Gross Domestic Product

GEF: Global Environmental Facility

IEA: International Energy Agency

ILO: International Labor Organization

MDC: Movement of Democracy and Change

MSD: Meteorological Service Department Zimbabwe

PV: Photovoltaic

SSA: Sub Sahara Africa

UNDP: United Nations Development Program

WTP: Willingness to Pay

ZANU-PF: Zimbabwe African National Union-Patriotic Front

ZESA: Zimbabwe Electricity Supply Authority

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Introduction

Around 1.3 billion people in the world currently have no access to electricity; almost a third of this group lives in Sub-Saharan Africa (SSA) (IEA, 2011). This reality where a majority of the population has no access to electricity is a barrier towards socioeconomic development. The lack of access to electricity leads to a dependence on lower quality energy sources like firewood, paraffin/ kerosene and candles for lighting and cooking abilities. Most households without access to electricity live in the rural areas where no funds are available for grid construction or extensions (Nguyen, 2006). The households that have access to the grid encounter many power cuts due to corruption and the shortage of supply (FEMA, 2006). Therefore solutions to increase electrification rates should be found in off grid or mini grid opportunities. With the abundance of solar radiation in SSA, solar energy seems to be one of the leading possibilities to give households access to electricity.

Problem statement

Zimbabwe is a landlocked country in southern Africa with a population of 12.6 million people spread over 2.6 million households (Factbook, the world factbook, 2011). In the rural areas 81% of the households have no access to the electricity grid (Davidson & Mwakasonda, 2005) (Central Statistical Office, 2004) (UNDP & WHO, 2009). Households mainly use fossil fuel based systems and car batteries for their energy consumption. This absence of access to modern energy sources is a major problem of economic development in Zimbabwe. Electricity is scarce and due to low internal power generation around 45% of its electricity needs to be imported from neighboring countries (ESMAP, 2000) (Karekezi, Kalumiana, & Mangwengwende, 2003).

Solar energy came to Zimbabwe in the eighties and was seen as a viable alternative to the grid. In the early nineties a large subsidy program was set up by the Global Environmental Facility (GEF) to increase the use of solar energy. This so called GEF program invested more than 7 million US$ in the solar PV sector in Zimbabwe (Mulugetta, Nhete, & Jackson, 2000). Many new businesses emerged and solar PV installation grew from almost nothing up to 10,000 during the period of the GEF program. In 1997 the GEF program finished and subsidies were stopped. Half a year after this subsidy stop more than 90% of domestic solar companies disappeared from the market (Mulugetta, Nhete, & Jackson, 2000). The solar industry was not able or willing to function without the subsidies from the GEF program. All money invested was gone and the solar energy market in Zimbabwe was back where it started before the program.

The rural market for solar PV in Zimbabwe is characterized by consumers facing various barriers and difficulties. Consumers have lost trust in the technology because of the flooding of relatively low quality inefficient products through the informal markets that are lowly priced (SNV_HIVOS, 2011). These products have been marketed to push the product without unpacking the capacity of the systems and investing in proper installation and maintenance of such systems. At the same time, rural consumers need to travel to town to have access to better quality product and services. This comes, however, at prohibitive prices. On average 30 percent transactions costs are added by urban based solar companies to do business in rural areas. Other major barrier for a rapid deployment of solar energy in rural electrification is the high initial investment cost of the systems, and the problem with affordable finance due to high interest rate of around 25% (African_Development_Bank, 2012).

An important precondition for the economic utilization of solar energy is the natural potential. With an average annual of 8.3 sun hours per day Zimbabwe seems to have a good climate for solar energy (MSD, 2012).

Research question

A large proportion of households in Zimbabwe have no access to electricity, there is an abundance of sun and former subsidy programs have failed. Therefore this research aims to find out whether there are possibilities for the development of a sustainable market based solar energy sector in rural Zimbabwe. Rural households will be examined to see if solar energy is a good option to fight low electrification rates in Zimbabwe. Solar irradiation data will be used to test whether the climate and natural circumstance are in favor of solar PV. The main research question is:

What is the potential for solar PV in rural Zimbabwe; combining natural radiation potential and economical feasibility?

This question is divided into two parts. First the solar irradiation and electricity potential in Zimbabwe is examined to verify if the natural condition in Zimbabwe are suited to support solar energy investments. How suitable is Zimbabwe's climate for electricity production with solar PV. The angstrom method and PVGIS data are used to answer the sub research questions:

- What is the spatial distribution of sun hours and solar irradiation throughout Zimbabwe?
- What is the electricity production potential of solar PV in Zimbabwe?

Part two studies economical feasibility of solar PV. First the current state of energy use for lighting and entertainment in rural areas is studied. After this a willingness to pay study is conducted to gain insight into the willingness of households to pay for solar energy products. This is important for companies to see if a sustainable investment opportunity (without subsidy) in this market is a feasible possibility. The results of the WTP for solar products are combined with data on income and market size to predict potential market value. Sub research questions are:

- What is the current state of energy use for lighting and entertainment in rural areas?
- What is the willingness to pay for three different solar products? Distinguishing between WTP for purchase and for rent to buy scheme.
- Is there a relation between the current energy use, income, household composition and WTP for solar products?
- What is the economical market potential for solar energy in selected rural areas, linking WTP, capacity to pay, and market size?

Contents

Chapter 1 provides background information on Zimbabwe; information on the research area, demographics, economy, energy situation, solar energy market and climate factors. Chapter 2 gives a description and explanation of the used methodologies. Chapter 3 shows the result of the natural potential for solar energy in Zimbabwe. Is Zimbabwe's climate suitable for solar energy. Chapter 4, 5, and 6 show the results for the household survey and contingent valuation method. Finally the main conclusion will be summarized and discussed.

1. Background

1.1. Introduction

The first chapter provides background knowledge on three important aspects of this thesis, Zimbabwe, the energy industry and solar PV.

1.2. Country Information

1.2.1. Research area

Zimbabwe is a landlocked country located in southern Africa, situated between the Zambezi and Limpopo river (figure 1.2.1). It has borders with Namibia, Zambia, Botswana, Mozambique and South Africa and its capital is Harare. The country covers a surface area of 390.000 square kilometers; this is almost ten times the size of the Netherlands. The country is divided into 10 provinces which are split up into 59 districts and 1200 wards. The largest part of the country is situated on a central plateau at altitudes between 1200 and 1600 meters. Exceptions are the lower Zambezi and Limpopo river valleys (below 500m) and the higher mountainous eastern part of the country (up to 2600 meters).

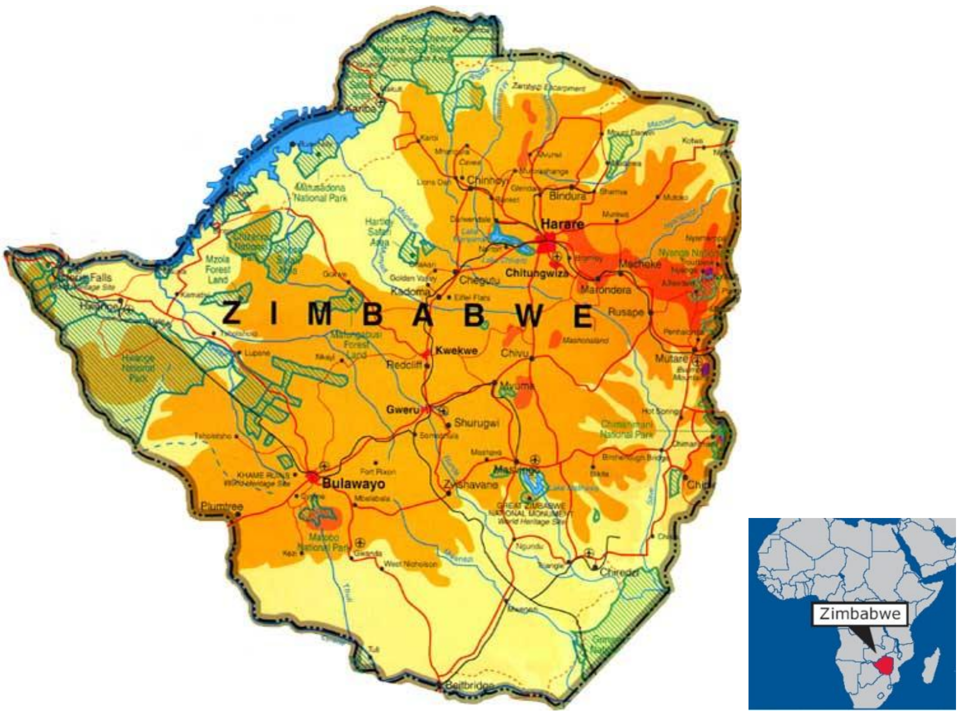


Figure 1.2.1: Geographical map of Zimbabwe (red-grey.co.uk, 2011)

1.2.2. Population

Zimbabwe has an estimated population of 12.52 million people of which 1.5 million live in the capital Harare. Total population in the five researched districts is 700.000 people (ZIMSTAT, 2002). The two largest black ethnic groups in Zimbabwe are the Shona (70%) and the Ndebele (25%) people. Ndebele people mainly live in the southwestern part of the country around Bulawayo; they have a strong aversion against the current regime and are therefore more affected by the economic downturn (Lindgren, 2002). White Zimbabweans are one of the minority ethnic groups, who account for approximately 0.5% of the population. The white population dropped gradually from 278,000 in

1975 to 120,000 in 1999 and less than 50,000 in 2002 (Wiley & Isaacman, 1981) (Shaw, 2003). Life expectancy is with 49 years one of the lowest in the world (World Bank, 2010). The main reasons behind this are the cholera epidemic and the high number of people with HIV/AIDS (WHO, 2009). 68% Of the people in Zimbabwe lives under the international poverty line of $1.25 per day, with an estimated average GDP per capita of $314 in 2009 (CIA, 2009) (UN_Statistics, 2009).

1.2.3. Economy and politics

Today's President of Zimbabwe Robert Mugabe was elected in 1980 after a violent struggle for independence. His party ZANU-PF (Zimbabwe African National Union-Patriotic Front) is characterized by repression, persecution, violence, corruption and widespread human rights abuse keep the population under control (Human_rights_watch, 2010). After bad election results in the late nineties Mugabe started with his famous land redistribution policy of reclaiming farms owned by whites and allocated them to black Zimbabweans. This policy triggered a collapse of the economy which a brought the highest inflation rates ever seen in the world. Inflation in 2008 is officially estimated at 165,000%, but unofficially it is estimated at 2.5 million percent a year. Over the whole 1997-2007 period cumulative inflation is estimated at 3.8 billion% (Hanke, 2008).

The 2008 presidential elections were won by the leader of the opposition party (MDC Movement of Democratic Change) Morgan Tsvangirai. Mugabe, however, ignored the results, and under international pressure a two-party government was formed by installing Tsvangirai as the Zimbabwean Prime Minister. But even after this violence, intimidation and oppression against Zimbabweans inhabitants continues. The opposition party MDC is still under attack and supporters have been killed and tortured recently (US.State_Department, 2009).

Figure 1.1.2 shows how the economy of Zimbabwe has shrunk significantly after 2000. After another 20% decrease in 2008 the economy now slowly starts to recover from its massive breakdown. The economic depression has also led to an official unemployment rate of approximately 80% in 2008 (Luebker, 2008).

1.2.4. Income

68% of the people in Zimbabwe live under the international poverty line of $1.25 per day (UN_Statistics, 2009). Except from this there is not much data available on income patterns in Zimbabwe. The latest numbers from the CIA factbook shows an estimated GDP per capita of $500 in 2011 and $314 in 2009 (CIA, 2009) (Factbook, the world factbook, 2011). The International Monetary Fund estimates GDP per capita in 2011 at $741 (IMF, 2011). These numbers are both average income per person, instead of income per household. According to the latest reliable national survey, the 1995–96 Income, Consumption and Expenditure Survey (ICES), mean rural annual consumption levels were Z$2,136 (US$217) per capita, with median consumption levels even lower, at Z$1,434 (US$146) per capita (Cavendish, 2000). A research done by HIVOS and SNV last year showed an average monthly income of $186 for rural households in Zimbabwe (ILO_SNV, 2012).

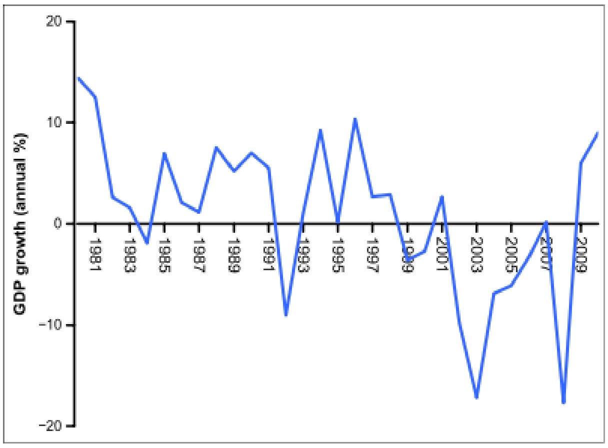


Figure 1.2.2: (Zimbabwe's annual GDP growth rate from 1980-2010(World Bank, 2010).

1.2.5. Local climate

The most important climate factor in Zimbabwe is the difference in the amount of rainfall throughout the year. The amount of rainfall influences the performances of agriculture, wildlife, and forestry throughout the country, more rainfall means higher productivity of agricultural land and therefore a higher income (Ministery_of_Environment, 2010). Figure 1.1.3 shows different rainfall zones within Zimbabwe; the green areas have a lot of rainfall (more than 1000mm/year) throughout the year and therefore are very fertile and suitable for specialized farming. The red areas have less precipitation (less than 650mm/year) and therefore are only suitable as an extensive farming region (OCHA, 2009).

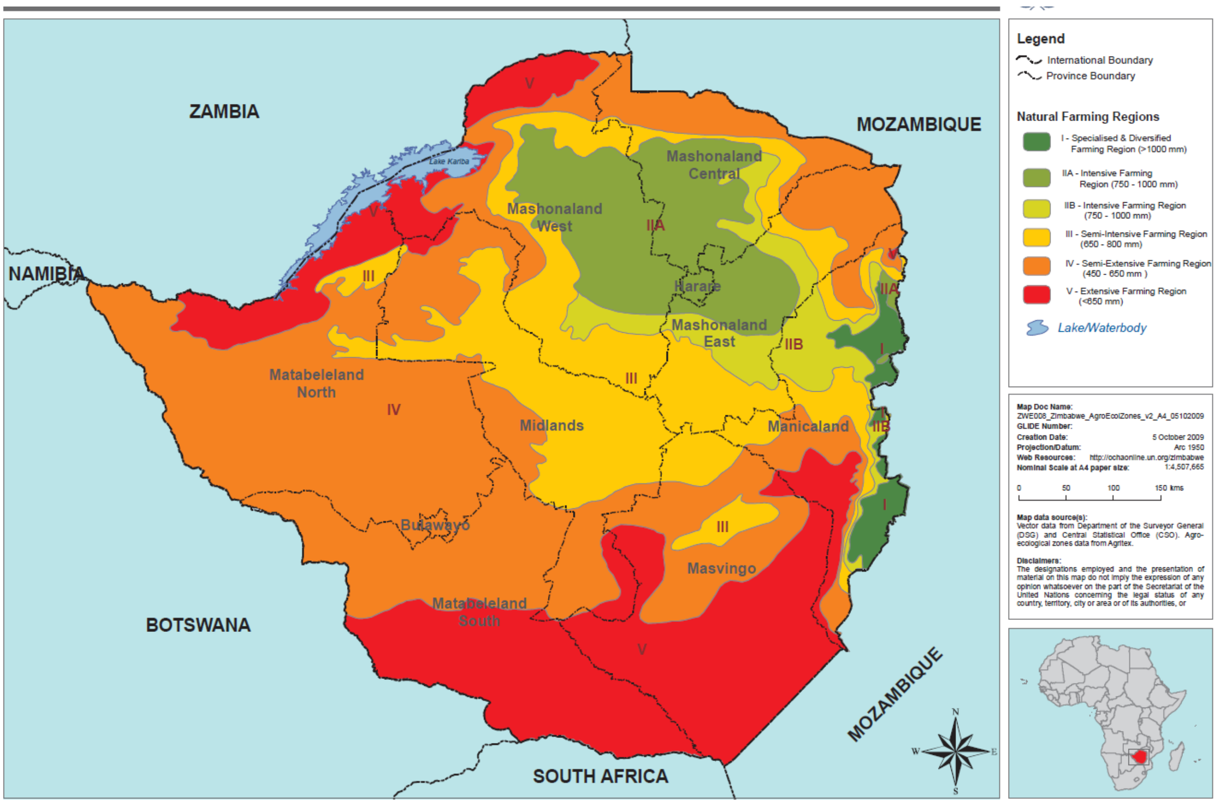


Figure: 1.2.3: Ecological zones map based on rainfall in mm/year (OCHA, 2009)

With a year round average of 8.3 sun hours per day is Zimbabwe one of the sunniest countries in the world. Especially the dry season between April and November is characterized by blue clear skies without any cloud coverage (MSD, 2012).

1.3. Energy

1.3.1. Zimbabwe's energy use

Zimbabwe makes use of several sources to meet their energy supply, biomass is the most important one and accounts for 50% of the total energy use. Over 80 percent of the population, mainly living in rural areas uses firewood for cooking, lighting and heating purposes. Coal (12%) and electricity (13%) are the other two main energy types which provide energy supply (RECIPES, 2006). The electricity generation and distribution is the responsibility of the Zimbabwe Electricity Supply Authority (ZESA). They use five large power plants with a total capacity of 1,961MW, of which the hydro plant in Kariba is the largest with a generation capacity of 500MW (Karekezi, Mapako, & Teferra, 2002). This energy production is not sufficient to satisfy the domestic demand, and therefore 41% of electricity demand is imported from neighboring countries. These countries are often also faced with a shortage in electricity production which leads to a power shortage and power cuts (Davidson & Mwakasonda, 2005). ZESA and the Zimbabwe government are therefore searching for solutions and investment possibilities to fight these supply shortage problems.

1.3.2. Solar energy in developing countries

Many developing countries have problems with their modern energy supply; in SSA more than 400 million people live without access to electricity (IEA, 2011). The developed countries in the world all have a reliable functioning electricity grid; this makes people often think the presence of a grid means that people have access to electricity. In reality the grid in developing countries is often very weak and unreliable, leading to power cuts that last several hours up to multiple days. Many people also find that developing countries should follow the same path as developed countries towards prosperity, which means the fast expansion of the electricity grid to electrify everybody. But as stated above expansion of the network does not necessarily mean a reliable supply of electricity. The reasons behind this are the lack of financial resources for adequate supply and maintenance of the systems. Therefore another model of energy generation is getting more and more popular. Off-grid energy production is a low cost, convincing and environmental friendly alternative for the current used large scale grid systems that are used in the developed world (Practical_Action, 2010). Solar energy is one of the possible energy sources that could be used in an off- grid system and therefore it is seen as one of the possibilities to fight low electrification rates in developing countries.

1.3.3. Solar energy market in Zimbabwe

One of the aims of this research is to develop a sustainable rural energy market in Zimbabwe; therefore it is of importance to get a better insight in the current solar energy market and its players. Solar PV market in Zimbabwe has predominantly been an urban market for the affluent, or the urban affluent who procure for their relatives in the rural areas. In addition, NGOs have formed the mainstay for providing solar PV in rural areas, of which the most notable one was the GEF project in the 1990's. In order to have a deeper understanding of the industry at large, a general survey was conducted by SNV of solar companies in Harare, Bulawayo and Mutare (Maphosa, 2012). Results below are derived from this survey.

From this survey it was noted that there are more than 20 solar companies with names in Zimbabwe. Of the identified companies 14 responded to the survey that was carried out. In this paper, the survey also noted that some companies carry two names to their portfolios as a way of diversification while other companies have since stopped operations for reasons not yet established. Some companies are not full time in solar resulting in them not recognized in this survey. An exact number of solar companies in the country cannot be established at this point because some companies sell solar products as a shelf product and many companies are opening up solar on backyard marketing. The solar industry in Zimbabwe mainly imports all the products that make a complete system. This is because the main component of a solar system is the solar panel and this is manufactured under high technology of which the country does not have that technology as yet and not foreseeable in the near future. All solar companies are merely distributors and installers of Solar PV and Thermal Systems.

Most companies were established in the years between 2005 and 2011 and they mainly focus on the urban market. This is supported by the fact that ZESA produces not enough electricity to supply the current consumers that have access to the grid. The majority of the companies is based in the capital city with exceptional from one in Mutare and two in Bulawayo. This is because the capital city is the place where all ends meet at a center of all activities. While Harare has most solar companies, prices have remained high despite high competition within the industry.

Most systems sold are 70-100W in size capacity of powering a television set, radio and up to 6 lights on either back-up or stand alone. There are also large sales of 20-30W systems for gate systems in the elite suburbs of the capital city and also for peri-urban areas where some small medium enterprises (youths in particular) have embarked on the establishment of cell phone charging stations as a source of income and later used for lighting in their homes at night.

In carrying out this survey, telephone calls were first made to locate companies that were still operating through contact details which were located. Companies in Harare that indicated availability were kindly asked to make time for an appointment with Gladys Maphosa to meet with the Manager and Sales Officer of the company. The survey questionnaire was sent via email to the companies in Bulawayo and Mutare and some other companies that could not make time within the proposed time of interviews.

This study focuses primarily on rural areas, for that it was decided to invite the solar companies for an interview to see what their opinion and knowledge of the rural market is. These interviews were designed by me during my internship with SNV. Interviews took place in collaboration with my colleagues from the renewable energy team Gladys Maphosa, Fungai Matura and Chandi Mutubukimakuyana. A complete overview of the agenda discussed during these meetings and reports of the interviews can be found in Appendix I.

Of the 14 companies that were surveyed, 7 were available for the interviews to talk about solar energy in rural areas, and selection within the SNV-ILO program. All companies indicated that they see clear opportunities and potential for sales of solar energy products in rural areas. But despite this great potential, all these companies have not yet chosen to largely invest in the rural areas. They are not sure that rural households have enough money available to purchase solar energy products. They think it necessary to develop payment schemes to ensure that households can invest in solar home systems. Another problem is the availability of loans and high interest rates. Interest levels are even for companies well over 25%, this makes it difficult to make high upfront cost and invest for example in first stock.

By examining the WTP of rural households this research will contribute to stimulation of investment by energy companies in the rural market. The results of this research will be presented to the companies to help them convince and work together with them to develop the rural solar energy market.

1.4. Solar PV

1.4.1. PV Systems

Photovoltaic systems are used all around the world to generate energy for houses, offices, and public buildings. Worldwide energy generation through solar photovoltaic (PV) has grown strongly in 2010. In 2010 the world's energy production with solar PV was approximately 40GW; 17GW of this total was added during this year (REN21, 2011). PV panels are cells that convert sunlight into electricity; each cell contains layers of semi conducting material. Electricity starts flowing through the solar radiation that creates an electric field across the layers. The amount of energy generated is determined by the intensity of the light. Electricity is generated not only with bright sunlight but also from reflected sunlight on cloudy and rainy days (EPIA, 2011).

1.4.2. Solar Radiation

The solar energy that the sun radiates every hour is potentially sufficient to ensure one year world energy consumption. This is the case when all sunlight is captured and completely converted into electricity. Using current solar PV techniques leads to an average solar radiation potential of 1700 kWh per square meter on earth. Therefore hypothetical total solar energy potential worldwide is sufficient to meet the existing global energy use over 10,000 times (EPIA, 2011). There are spatial differences in solar potential; the best locations are the subtropics with an average energy received up to 2,400 kWh/m2/year (figure 1.4.1).

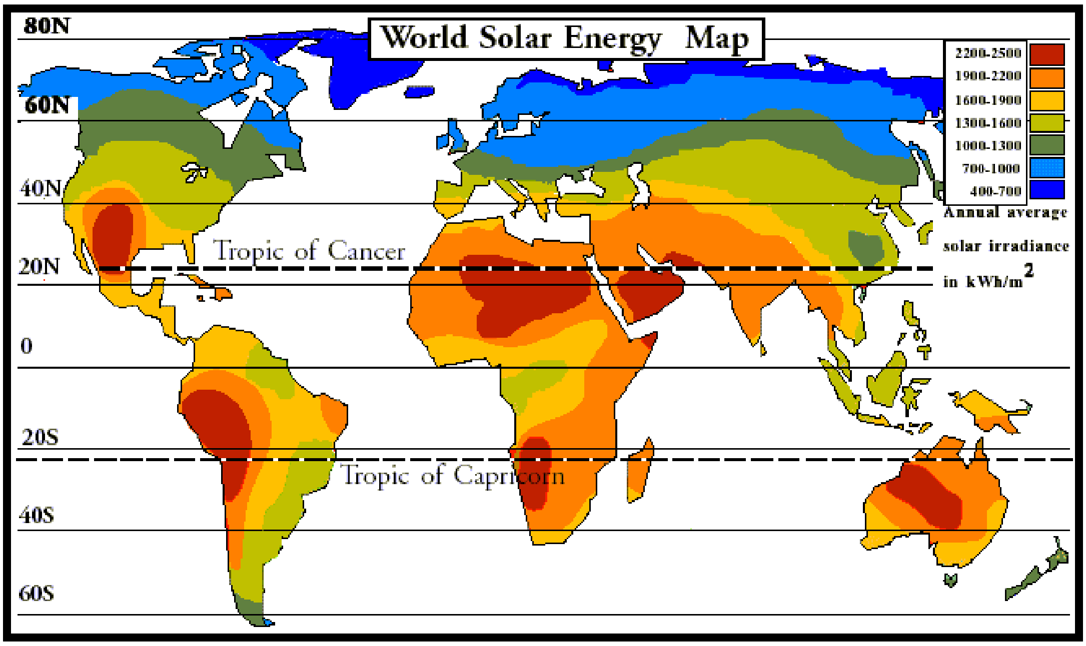


Figure 1.4.1: Worldwide annual solar irradiance (INFORCE, 2012)

1.4.3. Cost of solar PV

To see if WTP of rural households is realistic in comparison to the actual price of solar products we will try to give an overview of the price range from the selected products. It should be taken into account that there is a large price difference between products of different qualities. It should also be noted that prices for a region like Zimbabwe sometimes are higher due the high transport and other additional cost. The solar market is changing fast, international prices for solar panels dropped in 2011 by more than 50 percent. This makes it difficult to give a clear view on actual price for certain solar products.

The solar lantern that we used in our research as product 1 can be purchased by d.light from $7 up to $10 depending on the number of products you buy (d.light, 2012). Products of other companies are mostly a bit more expensive ranging from $10 to $20.

The solar lantern plus additional cell phone charger that we used as product 2 can be purchased by d.light from $20 to $30 depending on the number of products you buy (d.light, 2012).

It is difficult to give the price of a solar home system, because of the different components (batteries, converter and panels) and a variety of products. However, a similar solar home system like we presented as product 3 will cost around $230 in Bangladesh. Outside Asia, costs tend to be higher. In Ethiopia a 10W system costs about $260 and in Nicaragua a 50W system is sold for $600 (Weldom, 2012). An expert within SNV expects that a 30W system would cost around $500 in Zimbabwe.

2. Methodology

2.1. Introduction

This chapter describes and discuss the methods that are used in this research. Through two different paths, the natural and economic potential of solar energy in rural areas in Zimbabwe is examined (Figure 2.1.1). First the natural potential is examined to see if natural conditions are suitable for solar. Data from the meteorological institute in Zimbabwe is used to calculate irradiation in kWh/year. The results are checked with satellite data from the PVGIS program. GIS software is used to construct maps with solar energy potential in different geographical areas. After this two household surveys are conducted to investigate the economic potential for solar energy. The first survey covers the current energy use of households. The second survey studies willingness to pay for solar products. The economical potential for solar energy is derived by linking WTP and income results to actual market size.

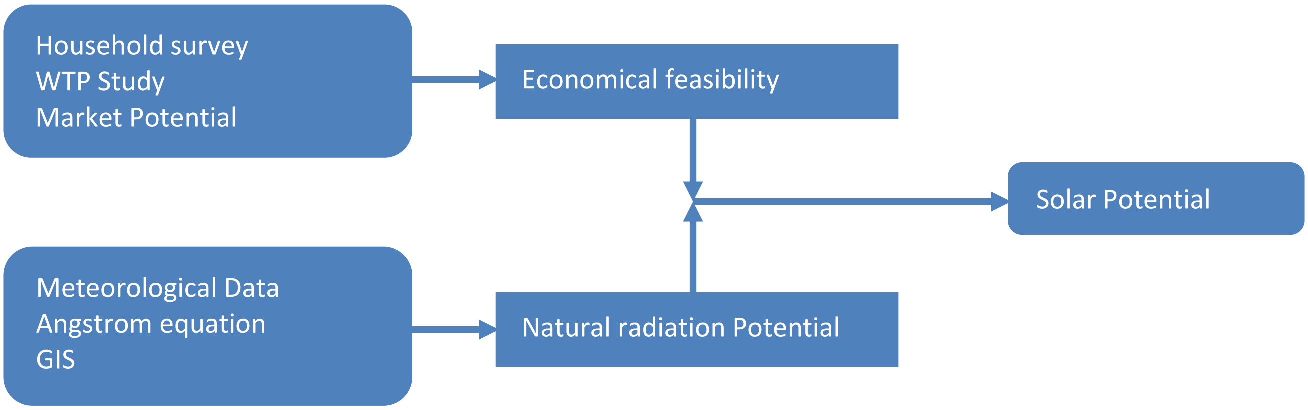


Figure 2.1.1: Overview methodology

2.2. Natural radiation potential

2.2.1. Introduction

The most common variables to measure solar radiation are solar radiance and solar irradiation. Solar radiance is an instantaneous power density measured in kW/m2. Solar irradiation is the total solar energy for a certain location within a specific time range measured in units of kWh/m2/day (Almorox & Hontoria, 2004). Radiance data is measured with a pyranometer (measuring global radiation) or a pyrheliometer (measuring direct radiation). Pyranometers and pyrheliometers are not available in most developing countries due to the lack of financial resources (Almorox & Hontoria, 2004). Therefore, in many cases sunshine hour data is used in order to compute solar irradiation in kWh/m2/day. In this research the Angstrom equation is used to estimate solar radiation per square meter per day. We make use of 30 year long-term averages for sunshine hours per day data from the Meteorological Service Department in Zimbabwe (MSD, 2012). The following research steps will be made to compose a solar radiation map for Zimbabwe:

1. Data from the meteorological service department is available for 39 stations around Zimbabwe. First step is to convert the data per station towards a value of average sun hours

per district (Distribution of 60 geographical areas in Zimbabwe). The closest available meteorological station data is used as a value for every district because H has to be estimated from close by stations with similar geographical features (Falayi & Rabiu, 2005).

2. Calculation of Global solar radiation (H) using the angstrom equation.
3. Compare Global solar radiation per day met data van PVGIS global solar radiation per day.

ARC GIS is used to present the data.

2.2.2. Angstrom equation

The angstrom equation was introduced by Angstrom in 1924 (Angstrom, 1924), and presented the relationship between daily global irradiation (H) and sun hours per day (Yang, Koike, Huang, & Tamai, 2007).

Angstrom correlation equation was used which defines global solar radiation where H is global solar radiation in J/m2/day as:

$$H = H_0\left(a + b\left(\frac{s}{s_{\max}}\right)\right)$$

Where H_0 is extraterrestrial global solar radiation given as:

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin\phi \sin\sigma + \cos\phi \cos\sigma \sin\omega_s\right]$$

Where Gsc is solar constant = 1367 W/m2

dr → inverse relative Earth-Sun distance =

$$(d_r = 1 + 0.033\cos\left(\frac{2\pi n}{365}\right))$$

n is the number of the day in the year between 1 and 365 or 366.

ωs is sunset hour angle = $arcCos(-\tan\sigma * \tan\phi)$

ϕ and σ are latitude and declination angle respectively $\left(\sigma = 0.409\sin\left[\frac{2\pi n}{365} - 139\right]\right)$

a and b - regression constants

S is measured sunshine hours and Smax is daylight hrs [= 24/π*ωs {OR = 2/15*ωs (where ωs is in deg)}

2.2.3. PVGIS

Solar irradiance is not only measured with ground equipment like the pyranometer or calculated via sun hour's data. Currently also satellites are used to estimate global irradiance (H). The satellite based information system PVGIS is used a second opinion to test the outcome of our angstrom analysis.

Photovoltaic Geographical Information System (PVGIS) is a satellite database estimating solar irradiance for larger areas in Europe and Africa. Mainly the database is used to calculate potential yields for solar energy. The PVGIS solar irradiation data for Africa was obtained by the HelioClim-1 database, estimated from MFG satellite data with a spatial resolution of 15. The time period of the data is 1985-2004. (Suri, Huld, Cebecauer, & Dunlop, 2008) (Barhdadi & Bennis, 2011).

Within the PVGIS database it is possible to request irradiance data for any exact location in Zimbabwe. To compare the PVGIS data with the calculations based on the number of sunshine we use the same spatial areas (districts). The main settlement within every district is used as location to obtain the data. Therefore this method makes use of 60 different data sets.

2.2.4. Total Natural solar PV potential

Solar irradiance is calculated with the help of the angstrom equation and sun hour's data from meteorological service department Zimbabwe. This data is compared with satellite data from PVGIS data base.

Total natural potential for solar PV in the rural areas of Zimbabwe is calculated with the help of the following factors:

1. Solar irradiance: ____
2. Annual electricity production per m^2 per year with average solar panel → efficiency of solar cells
3. m^2 of panels per households

Average solar irradiance is used to calculate electricity production per square meter per year. The efficiency of solar panels needs to be taken into account. The most commonly used solar panels have efficiency up to 25% in the laboratory. In commercial use efficiency is between 14-20% (Hermans, 2008). The efficiency of solar cells is so low because not all light is effective in releasing electrical charges. The most used silicon solar cells only work optimal in near infrared light. Light with a longer wavelength contains too little energy and light with a shorter wavelength produces too much energy, which is released as heat (Andrews & Jelley, 2007). Solar irradiance is multiplied with an expected average efficiency of 17%. Multiplied with the number of households results in an estimate of the total natural solar potential in electricity production in kWh per year per m^2 (figure 2.2.1).

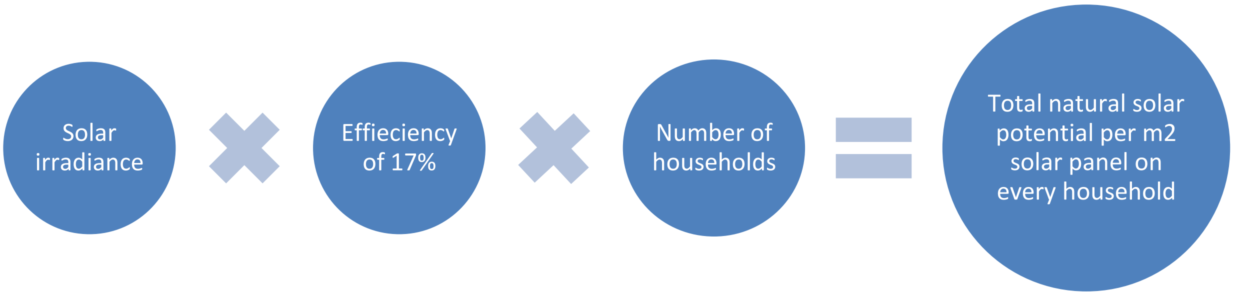


Figure 2.2.1: calculation natural potential per m^2 solar panel

2.3. Economical feasibility

This part of the thesis examines the economic feasibility of solar energy for rural areas in Zimbabwe. The methodology consists of a household survey, a WTP study and a market potential analysis using market size, WTP and income.

2.3.1. Site and sample selection

Two interviews (Appendix II and III) have been conducted among 288 households in five rural areas around Tsholotsho, Mt Darwin, Mutasa, Gokwe, and Mutoko (figure 2.3.1). The five locations are chosen by ILO on the basis of field officer's availability in these districts. The interviewed households are selected on the criteria: substantial distance from the main road and no access to the electrical grid. Besides those two conditions the households are randomly selected on the basis of availability. These two criteria were chosen as the target of this research consists of households without access to electricity that live in rural areas. Settlements along the main road have been excluded because they often have access to electricity.

Due to the chosen group, the results will not represent the entire rural population, but only that group that has no access to electricity

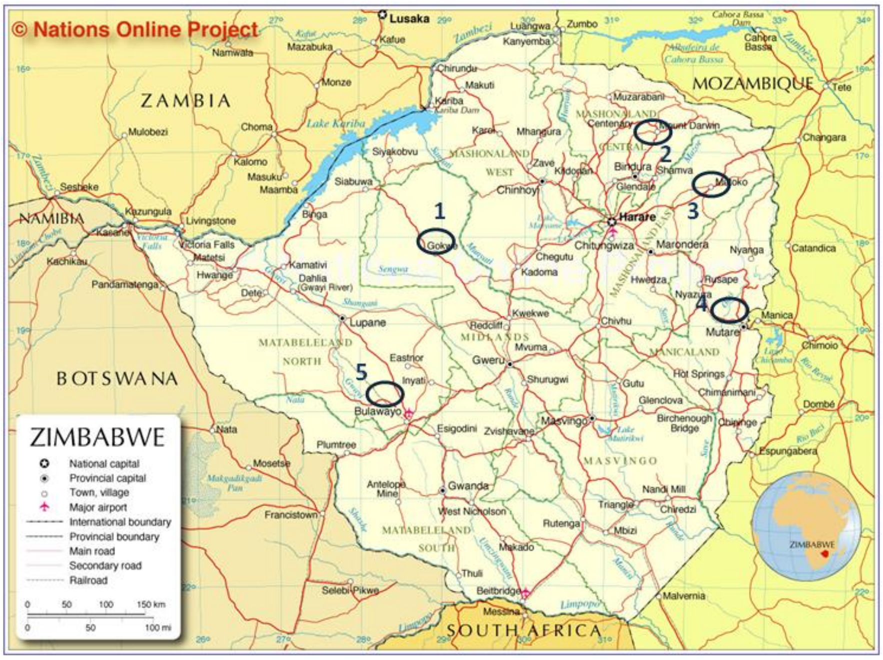


Figure 2.3.1: Research areas

2.3.2. Household surveys

The main objective of the first survey (Appendix II) is to gather general household information on the current energy use. Furthermore general demographics and information will be obtained. The second survey has been conducted among the same 288 households as the first survey. This allows us to use the results of both studies together for data analyses.

The surveys were administered to 288 different households by district field officers from the 'Training for Rural Economic Empowerment' ILO program between 14 April and 28 May, 2012 in the indicated locations (figure 2.3.1). This was after an initial process in each district with the field officers and author to test the survey and do trainings on the data collection methodology and WTP approach. In total 10 enumerators were involved in the process of data collection.

2.3.3. Willingness to pay study

Willingness to pay (WTP) is an economic term that has various definitions, but the most common states that:

"WTP is the maximum amount that an individual state they are willing to pay for a good or service" (DFID, 1998)

There are two different ways to estimate WTP; revealed preference and stated preference. Revealed preference is a method that observes the actual price people pay for a good. An example of a revealed preference is the hedonic pricing method were house prices are used to estimate peoples willing to pay for environmental goods. Stated preference techniques ask people what they are willing to pay for a certain good or service in the future. People are asked a hypothetical question about their willingness to pay. An example of a stated preference method is the contingent valuation methodology (Wedgwood & Sansom, 2003).

Contingent valuation (CV) is economical technique that is mainly used for the valuation of non-market goods like for example the value of biodiversity and clean air. In contingent valuation surveys are used to ask people directly how much they are willing to pay for a certain good or service (Wedgwood & Sansom, 2003).

In this research a contingent valuation is used to directly ask household their maximum willingness to pay for three different solar products. Contingent valuation is used because most households in the rural areas of Zimbabwe have no easy access solar products. The availability and quality of products is low, and households have to travel long distances to buy solar products (SNV_HIVOS, 2011). Therefore there is not much market data available that could be used for the valuation of electricity products. Rural households in Zimbabwe have no access to electricity; this is a hypothetical market that not yet exists in these rural areas (Abdullah, 2009). Contingent valuation is used before in development countries to estimate WTP for renewable energy products in Kenya (Abdullah, 2009) (Abdullah & Markandya, 2012), South Korea (Ku & Yoo, 2010) and India (Roy & Jana, 1997). Comparable and useful other contingent valuation studies are done in the field of water and sanitation (Al-Ghuraiz & Enshassi, 2005) (Gunatilake & Yang, 2007) (Luoto, Najnin, Mahmud, Albert, & Islam, 2011).

2.3.3.1. Payment cards

There are different ways of setting up a CV questionnaire for instance: open-ended, dichotomous choice, multiple-bounded dichotomous choice, iterative bidding and payment cards (Kerr, 2000). In this research payment cards (Appendix IV) are used to elicit WTP values for 3 different solar products. Payment cards contained both a description of the product and different price options to purchase or to rent to buy the different products. Making use of payment cards to research WTP is an accepted method that is also used to research WTP of malaria medicines in Nigeria (Udezi & Usifoh, 2010) and WTP for fair trade coffee in China (Yang & Hu, 2011).

During a payment card method households have to choose a value from a list which best reflects their WTP for a product or service. After being developed by Mitchell and Carson in 1981, the payment card method was mainly used in general economics (Ryan & Watson, 2009). It is said that payment card method simulates best real life by allowing people to choose a value that is a close as possible to their maximum WTP (Donaldson, Shackley, & Abdalla, 1997).

Three different payment cards are used to determine WTP for solar products. The solar products will provide the household with light and a certain amount of electricity for other purposes such as cell phone charging. By presenting the different payment cards the interviewer asks the following two questions:

a. How much are you maximum willing to pay to purchase the solar product that is described at product card 1-3?
b. How much are you maximum willing to pay every month to rent to buy the solar product that is described at product card 1-3?

Both questions have been asked for all products. The households are asked to keep in mind the amount of money they are spending at the moment on light and electricity, and to choose an amount of money which they can afford considering their current income levels. In this study it was decided to ask the WTP for three different products. This is done to examine the best investment opportunities for companies in the rural market. Should future entrepreneurs focus on simple products like solar lantern or advanced technologies such as small solar home systems.

2.3.3.2. Product specification

The WTP study was conducted for the following three products (figure 2.3.2):

	This is solar lantern with one light that will provide you with eight hours of bright light when fully charged. The lantern can be used for working, studying, cooking, walking and socializing, is portable and gives 360 degrees illumination. • Approximate cost: $10 • 3 Watt • Charging time battery: 10 hours • Hours of light: 4-8
	Is solar lantern and charger that provides you with 12 hours of light when fully charged. It can be used to charge your phone for approximately two hours per day. • Approximate cost: $25 • 3-5 watts • Charging time battery: 10 hours • Hours of light: 12
	A small solar home system that provides you with light from multiple lights as well the possibility to run a radio, small fan or TV. It can be used to charge multiple phones every day. Furthermore there is a possibility to extend the system with more panels when future situation will require this. • Approximate cost: $500 • 30 watt system • Charging time battery: 12 hours • Hours of light: 10

Figure 2.3.2: Product specification Payment card study

2.3.3.3. Statistical analysis

All data is processed using SPSS and Microsoft excel. The demographic and general variables are mapped using descriptive statistics. To test if there is a relationship between WTP for solar product with one of the other variables a correlation matrix is constructed and regression analysis has been done.

Pearson's correlation coefficient is used to test whether there is a relation between WTP and other variables. Pearson's correlation is a measurement of the strength of a linear association between two variables, basically a Pearson correlation attempts to draw a line of best fit through the data of two variables. Pearson correlation coefficient indicates how far away all these data points are to this line of best fit. The stronger the positive association of the two variables the closer the Pearson correlation coefficient will be to +1. A Pearson's coefficient between 0.0 and 0.3 means there is a small correlation. A coefficient between 0.3 and 0.5 is a medium correlation, and a coefficient higher than 0.5 indicates a strong relationship between two variables. The two variables can be measured in entirely different units (LEARD, 2012).

After this a multivariate regression analysis is done to see which factors influence WTP for solar products. The multivariate regression model specification is shown below. The dependent variable is the WTP for solar product in rural Zimbabwe (Three tests are done for the three different solar products). Independent variables are: Income ( ) expenditures ( ), number of minutes using the lighting system ( ), distance to grid ( ), nr of people living in a household ( ) and nr of kids attending school ( ). These variables have been included in this model because we expect they might influence the WTP for solar products. Earlier research showed that a higher income leads to a higher WTP (Lundberg, Johannesson, Silverdahl, & Lindberg, 1999).

WTP = f {Income, expenditures, number of minutes using the lighting system, distance to grid, number of people living in a household, number of kids attending school} (1)

WTP = (2)

Are the model coefficients for the independent variables ( ), e is the error term.

2.3.4. Market potential

Market potential for solar products depend on varies conditions. Three different factors are used to determine total economical market potential for solar products in the rural areas. First factor is the size of the market; in this case how many households are willing to buy solar products. The numbers of households without electricity are used as indicator for market size. Second factor is the amount of money people will spend on a product. The median willingness to pay for a solar product is used as indicator for expenditures on solar products. We expect that WTP and therefore the purchase of solar product is influenced by income. Only a certain group of household above a minimum income range will be able to buy solar products. This third factor is called capacity to pay. Capacity to pay is a factor of the total population earning above a minimum standard to buy solar products. In this research we exclude households as able to pay when they earn less than 4 times the cost of the solar product. We assume that households are maximum capable to spend 25% of their income in ones on a solar product.

Market size, WTP for solar products and capacity to pay are multiplied to calculate the total market value for solar product in rural Zimbabwe (figure 2.3.3). We zoom in on the 5 districts where market surveys are conducted because for these areas we know actual WTP and income ranges. Average WTP of the five research areas is used to estimate market potential of the whole country.

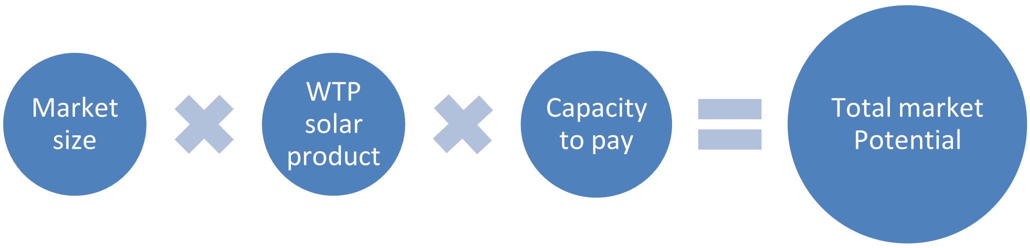


Figure 2.3.3: calculation market potential

3. Results Solar Radiation

3.1. Sun hours per day

Zimbabwe has an annual average between 6.7 and 8.9 sunshine hours per day (figure 3.1.1). In comparison, the Netherlands has an annual average of 4.3 sun hours per day. The west of the country gets the most sunshine, with averages up to 8.9 hours per day. The elevated east gets less sunshine as low as 6.7 hours per day. This difference in sunshine hours can be explained by the rainfall pattern throughout the country shown in figure 1.2.3. The fertile central and eastern parts of the country receive more rainfall which leads to a smaller amount of sun hours. The sparsely populated western part of the country receives more hours of sunshine than the denser populated east. This is of importance when we further examine natural potential in relation to the number of households.

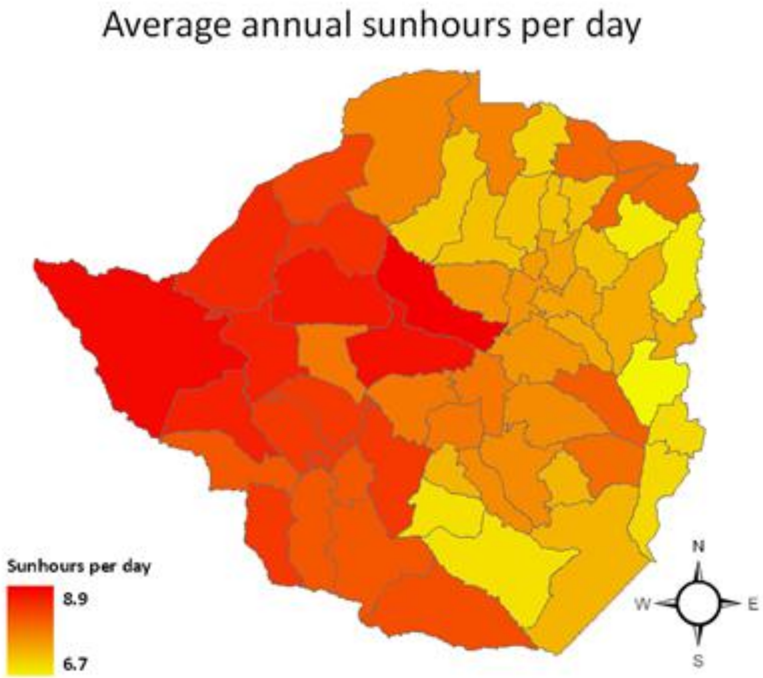


Figure 3.1.1: Average annual sun hours per day

Figure 3.1.2 shows average sun hours per day for the months august and December, respectively the months with highest and lowest number of sunshine hours. Average sun hours per day in December range from 5.3 up to 8.1. In August it ranges from 7.8 up to 10.5 hours per day. Seasonal variation is explained by the rain season and dry season. December is the middle of the rain season; August is the end of the dry season with virtually no precipitation. The sun hour differences in the south part of the country are also influenced by summer and winter day time differences. December is summer in the southern hemisphere with longer actual days. August is winter with shorter days with less hours of sunlight.

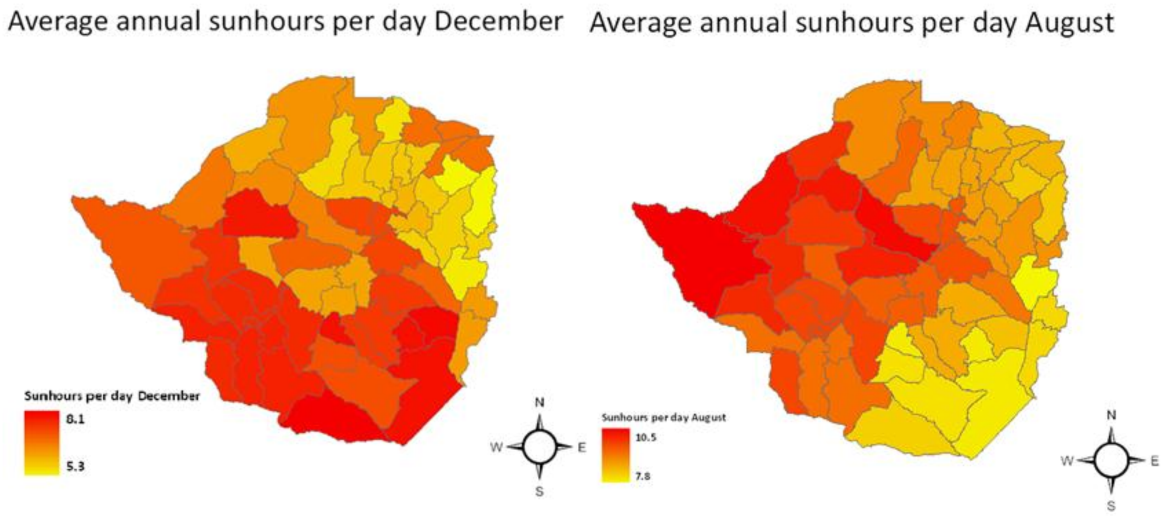


Figure 3.1.2: Seasonal variation in sun hours per day

3.2. Daily solar radiation (H)

Solar irradiance is between 1857 and 2257 kWh per square meter per year in Zimbabwe. The two different methods used to determine solar irradiance give two different outcomes. The angstrom method shows a less clear pattern and smaller absolute differences in solar irradiance (between 2257 and 2106 kWh/year). PVGIS method has a clear north-south distribution of solar irradiance with larger absolute differences between the lowest (1857 kWh/m2/year) and the highest (2161 kWh/m2/year) irradiance levels. Two methods are used to estimate solar irradiation. The left image in figure 3.2.1 shows the results from the angstrom equation. Number of sun hours per day from meteorological service stations is used to calculate solar irradiation in kWh/m2 per year. The right image in figure 3.2.1 shows the results from PVGIS. Satellites are used to estimate solar irradiance for every location in the country.

The overall results show a higher irradiance in the north and lower values in the south. This is expected because the closer to the equator the higher irradiance levels are. This is due to the angle of the sun relative to the earth. On the equator the same amount of solar energy heats a smaller part of the earth. Solar irradiance does not match sun hours per day; annual sun hours per day are distributed with an east-west division, and annual irradiance has a north-south distribution.

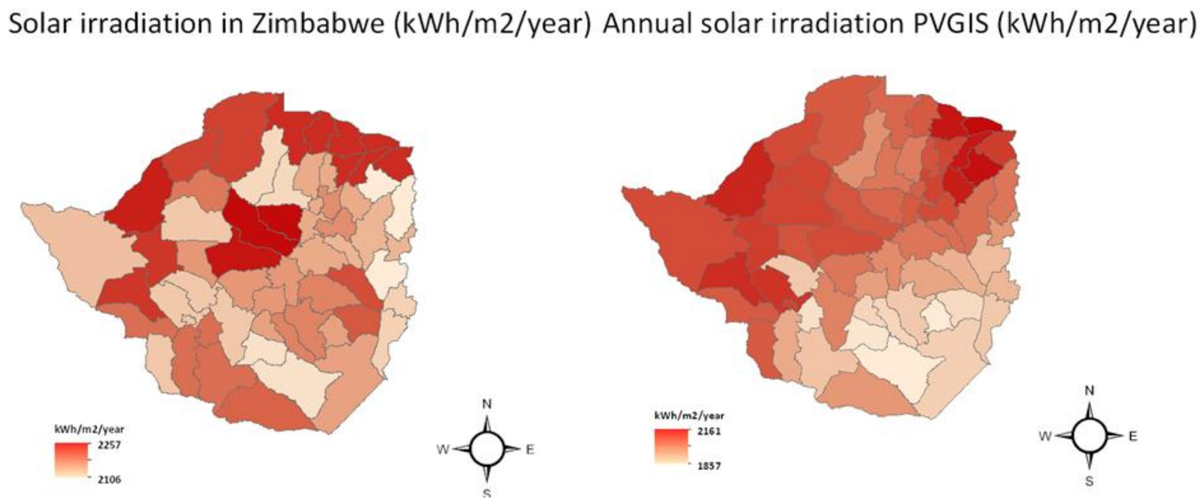


Figure 3.2.1: Annual solar irradiation (H)

Figures 3.2.2 (angstrom method) and 3.2.3 (PVGIS) show the seasonal variation in solar irradiance in June and November. June is the month with the lowest solar irradiance per month. Angstrom and PVGIS figures are similar to the highest irradiance levels in the north and lower values in the south. Irradiance levels vary between 120 and 150 kWh per square meter per month.

In November irradiation is the highest throughout the year, but the figures of angstrom and PVGIS are less similar. In the angstrom method irradiance levels are between 200 and 220 kWh/m2/month. The PVGIS satellite data show an irradiation range between 170 and 201 kWh/m2/month. The distribution is similar in the north and western part of the country with relatively high levels. The eastern part of Zimbabwe shows no clear pattern. PVGIS gives high levels toward the northeast and lower values in the Southeast. Angstrom method gives are more random distribution in the east, with low and high numbers randomly spread around. It should be noted that the absolute difference between the districts is not more than 20kWH/m2/month. Another reason for the differences might be the limited number of measurement stations that are used for the angstrom method.

The seasonal variations show that the differences between the Angstrom and PVGIS method are caused by the differences in the values of the month November, June values are almost identical.

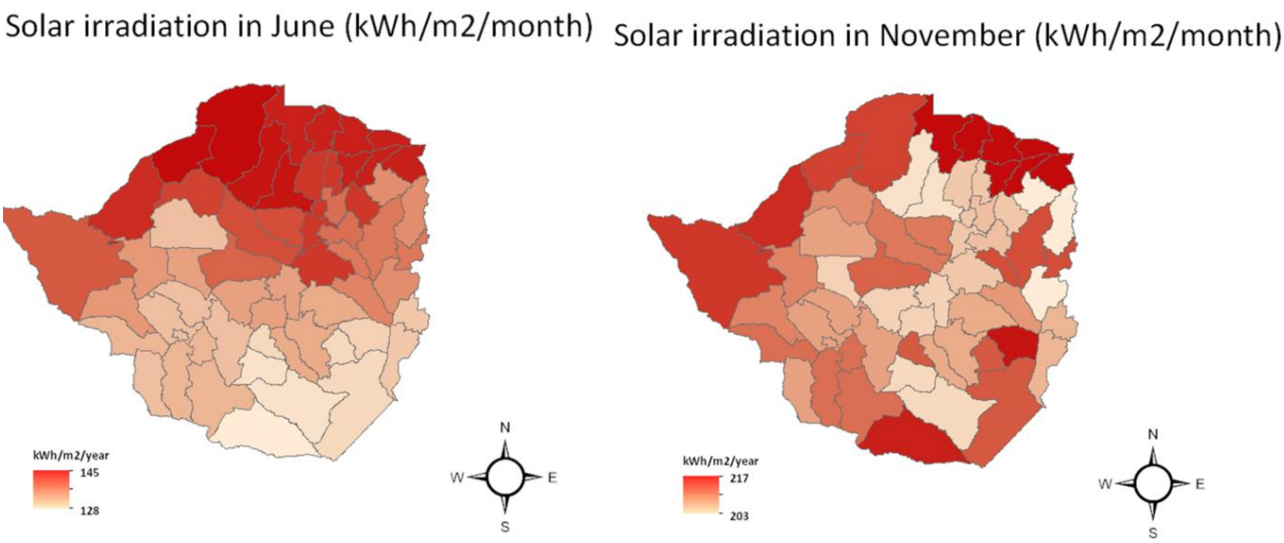


Figure 3.2.2: Seasonal variation in solar irradiation (H) angstrom method

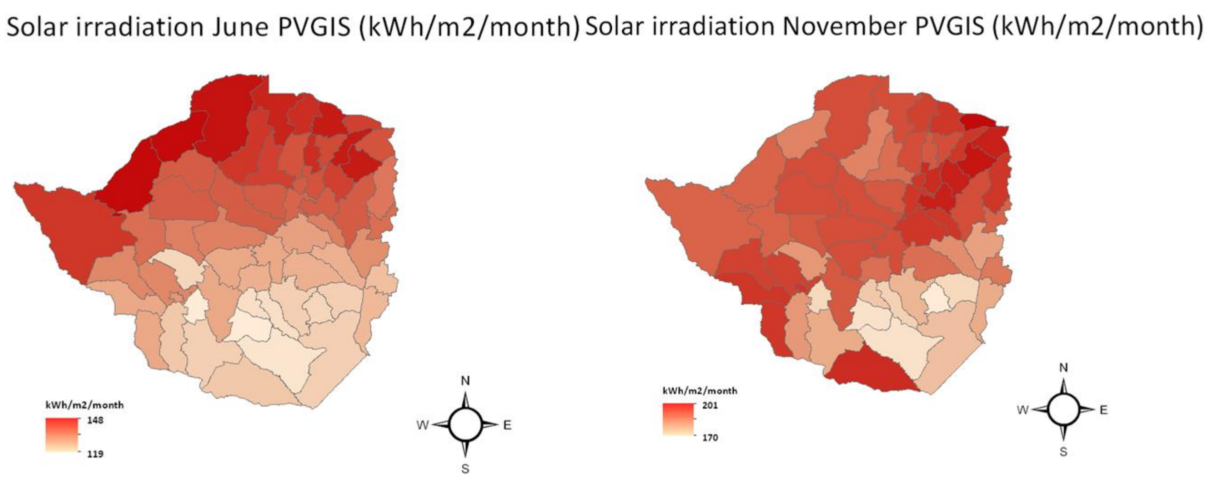


Figure 3.2.3: Seasonal variation solar irradiance PVGIS

3.3. Natural potential solar energy

Average solar irradiation in Zimbabwe over all 60 districts is 2112 kWh/m^2/year (average of angstrom analysis and PVGIS). Multiplying this by 17% average solar PV efficiency leads to an average electricity production for solar PV in Zimbabwe of 359 kWh/m^2/year.

Spatial variation in electricity production potential is displayed in figure 3.3.1. The pattern is as expected similar to the pattern we saw for solar irradiance. There is a clear north south distribution in electricity potential with maximum levels in the North of 375 kWh/m^2/year and lowest values in the south as low as 340 kWh/m^2/year.

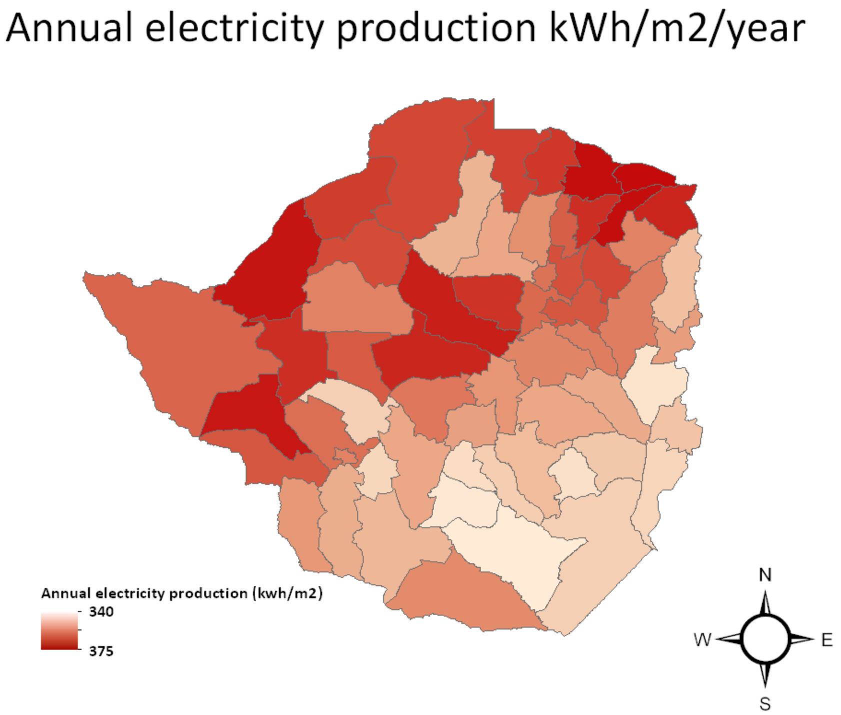


Figure 3.3.1: Annual electricity production kWh/m^2/year

Figure 3.3.1 shows natural potential per m^2 per year for every district. The total number of households is used to calculate the natural potential for solar PV. Zimbabwe has a total of 2.65 million private households (ZIMSTAT, 2002). Every m^2 solar panel per household has an average electricity production 359 kWh/year. Total average solar potential for Zimbabwe now depends on the number of m^2 of solar panels per household. Assuming every household installs 1m^2 of solar panels leads to a total annual natural potential of 951 million kWh. Figure 3.3.2 shows electricity production potential for every extra m^2 of solar panel per household.

Electricity power consumption was 10,286 million kWh in 2004 (World_Bank, 2004). This means that a minimum of 11m^2 of solar panels per household is needed in Zimbabwe to cover total current electricity power consumption.

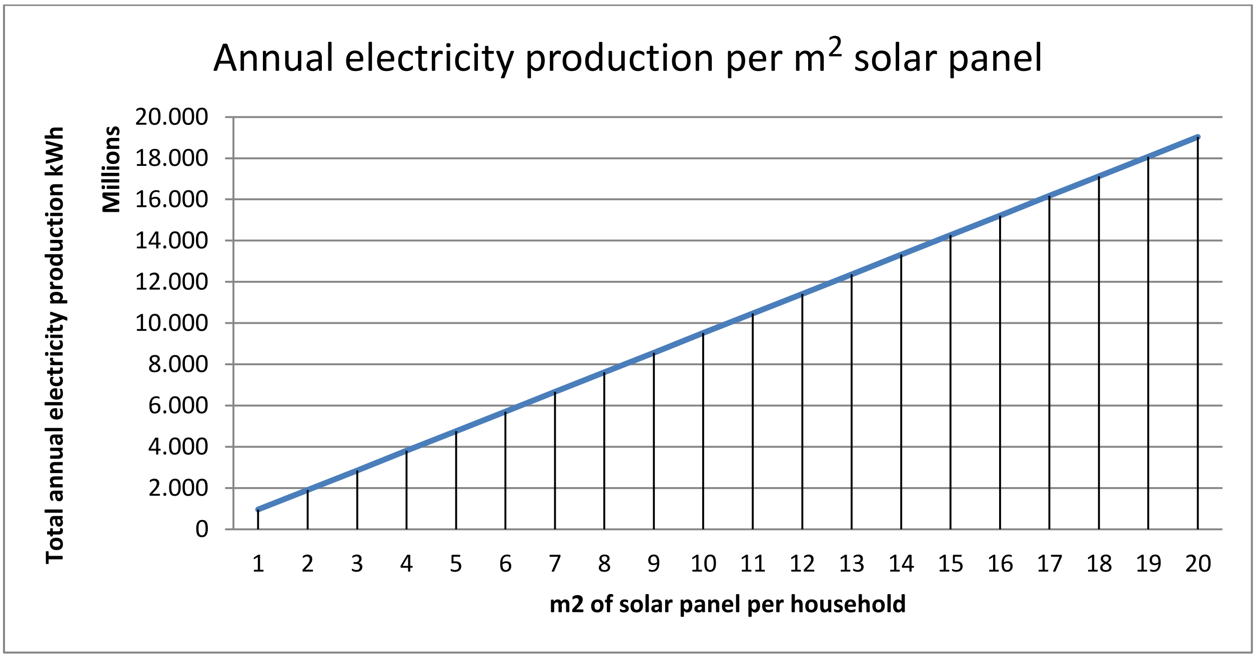


Figure 3.3.2: Annual electricity production per m^2 solar panel

However there are some limitations of solar PV that should be noted. Solar panels only generate electricity during the day. Electricity needs to be consumed directly after production. Electricity demand is highest during the evening and night. These are the times when there is no sunlight and solar electricity available. This means there is no match between demand (at night) and supply (during the day) of solar energy. A solution for this problem could be the storage of electricity. But on the moment the local storage of electrical energy is difficult. Batteries can be seen as the most obvious and easy solution, but batteries are expensive and environmentally unfriendly. Furthermore stored electricity is of low voltages which mean that devices and equipment needs to run on low voltage of 12 Volt.

The alternative could be the use of an inverter to create 230 V electricity. The surplus of generating energy could then be added to the electricity grid and used elsewhere in the country. At the moment the needed infrastructure for these kinds of systems is not available in Zimbabwe.

3.4 Overview results

The climate of Zimbabwe is suitable for the generation of solar power. Calculating information on sun hours towards irradiation levels leads to a an average yearly irradiation of 2112 kWh/m^2/year. An efficiency level of 17% leads to an average annual electricity production potential of 359kWh/m^2/year. In comparison the potential in the Netherlands using the same efficiency levels is approximately 170 kWh/m^2/year (Icon_Publishers, 2010). The potential for solar energy in Zimbabwe is double the potential for solar energy in the Netherlands.

For every m^2 of solar panel on all households the total electricity potential in Zimbabwe is 951 million kWh. A minimum of 11m^2 of solar panels per household is needed in Zimbabwe to cover total current electricity power consumption.

4. Results household survey

4.1. Demographics

A total of 288 households in five different regions have been interviewed in this research. Around 60% of the persons answered the questions of the interview was male, the other 40 % female. Rural Zimbabwean households consist of an average of 5.69 people. This figure is similar in all five areas. In comparison a report of ZIMSTAT from 2012 states that an average household in Zimbabwe consist out of 4.1 people (ZIMSTAT, 2012). The difference can be explained by the fact that rural areas consist in general out of larger households. Evidence of this statement can be found in a report about household composition in the developing world from 2001. It stated that on average urban households are smaller than those in rural areas. This urban-rural difference is mainly the result of a higher number of children per household in rural areas (Bongaarts, 2001). Forty percent of the household members are school age children; this is roughly the same figure as the 43 % that is announced in the ZIMSTAT 2012 report (Table 4.1.1).

Nr of Households	Total	Male %	Female %	No. People living in household	No. of school age children
Mt Darwin	60	51.7	48.3	5.38	2.22
Mutasa	56	60.7	39.3	5.38	2.61
Gokwe	52	53.8	46.2	5.63	1.52
Mutoko	60	70.0	30.0	5.82	2.57
Bulawayo	60	50.0	50.0	6.23	2.47
Total	288	57.3	42.7	5.69	2.29

Table 4.1.1: Households characteristics

4.2. Current Lighting

Paraffin based systems are the most used lighting system; more than 80% of the households uses a paraffin based system to light their house. Torch light (34%), candles (24%) and wood fires (31%) are also systems that have been frequently used for lighting. Solar is used by ten percent of the households for their lighting consumption. Lighting is an important commodity for all households. It is needed in the evening during cooking, studying, preparing beds, outside work and social interaction. Figure 4.2.1 reflects which form of lighting system is used by the households to provide in their needs. A large part of the households use a combination of local paraffin lantern, candles and wood fires. The local paraffin lantern (lamp based system without glass cover) is used by almost seventy percent of the households; an extra ten percent of the households use normal paraffin lanterns. There is no information from previous research about energy demand specifically for lighting purposes. All reports focuses on total energy demand, for example a research from SNV showed that 69% of rural household's uses paraffin in their energy mix (SNV and HIVOS, 2011). This figure is similar to number we found in this market assessment, and proves the significance of the obtained figures. Looking into all energy consumption, solar energy is used by 24% of the households (SNV and HIVOS, 2011). Most household uses their solar energy to provide energy for radio and charging phones, as we have seen only 10 percent of the households is using solar for actual lighting purposes Not one of the interviewed household has access to the national energy grid. Therefore all households depend for their lighting demand on off grid solutions that could be paraffin based, battery based (including torch light) or renewable options like solar.

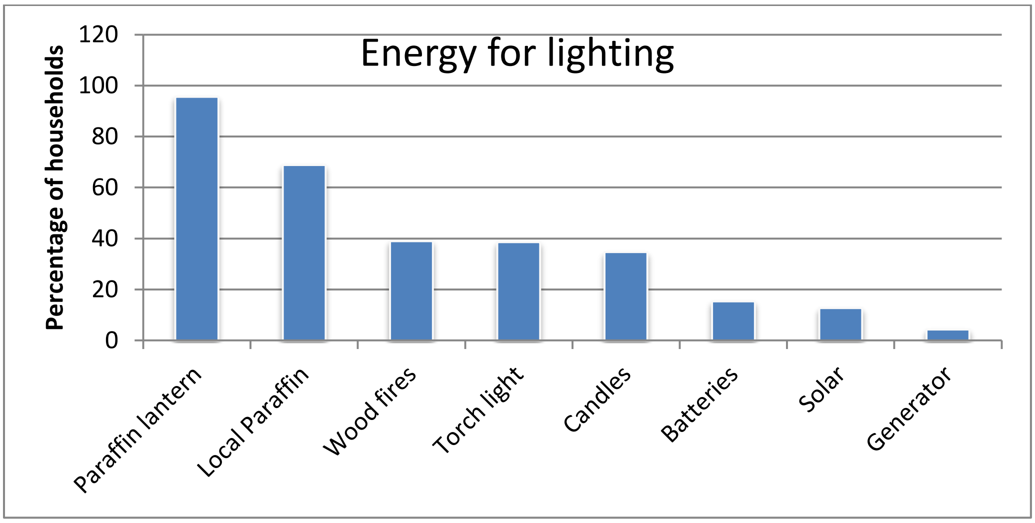


Figure 4.2.1: Energy source for lighting

Figure 4.2.2 shows the differences in energy use for lighting purposes between the 5 different regions. The regions are broadly in line but it is notable that the Gokwe area differs most from the other areas; it is characterized by the large use of batteries and torch lights for their lighting systems.

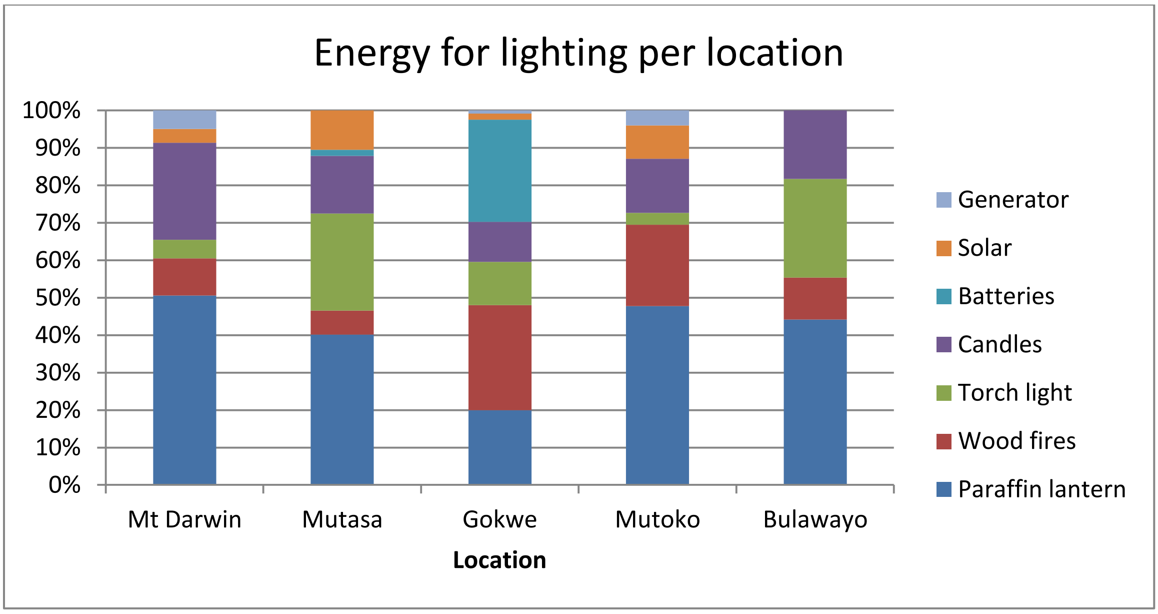


Figure 4.2.2: Energy source for lighting per location

On average the lighting system is used for 206 minutes (3 hours and 26 minutes) per household per day (Figure 4.2.3). Mutoko difference from the other regions, here they use the lighting system on average for almost 350 minutes in comparison with an average use between 100 and 150 minutes in Gokwe, Mutasa, Bulawayo and Mt Darwin. It will be interesting to see if there is a relation between the number of minutes the lighting system is in use and income of a certain household. We also expect to see differences in the willingness to pay in relation with minutes of lighting system use. After the second survey we will see if there is a significant relation between income, willingness to pay for solar products and the minutes of lighting use. More than 3 hours per day of lighting use indicates a substantial demand and market for lighting products.

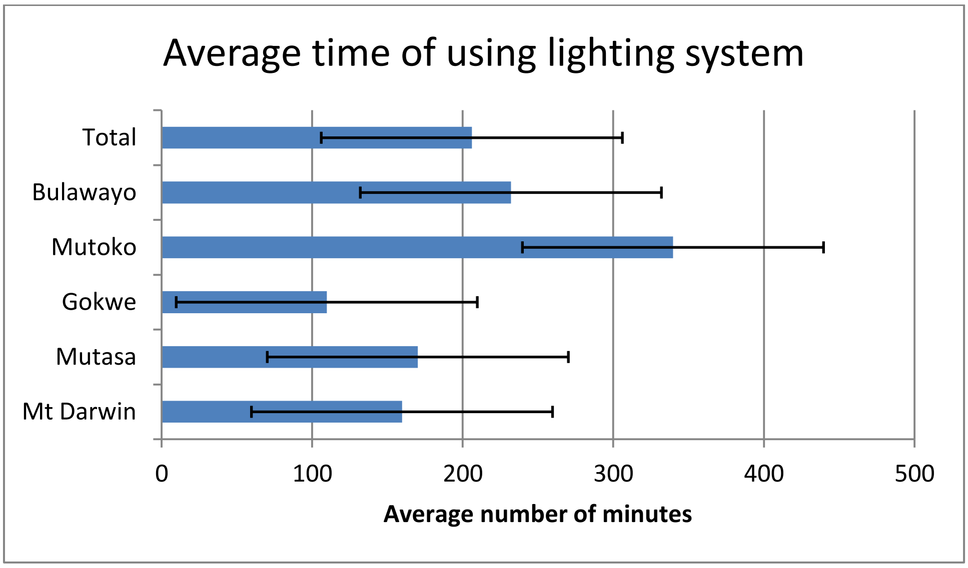


Figure 4.2.3: Use lighting system

4.3. Paraffin

Figure 3.2.1 showed that more than 80 % of the households are using paraffin lanterns to light their houses; this number correlates with the 73.2 % of the households that buy paraffin. An average household uses 0.44 liter of paraffin every week, this is bought every 6 weeks for an average price of $1.23 per liter (table 4.3.1). In comparison, a research done by the UN in 2004 shows an average paraffin use of 0.6 liter per week in the rural areas of Zimbabwe in 1988 (UN-DESA, 2004). Using these numbers we can calculate that on average households spend around $2 per month on paraffin.

Paraffin oil is usually called kerosene in Australia and the United States. Paraffin or kerosene is widely used in rural areas of Asia and Africa where electricity is not available. Paraffin or kerosene lanterns consume worldwide an estimated 77 billion liters per year (Bolay & Schmid, 2012). According to the United states energy information administration Zimbabwe used 2000 barrels of oil equivalent on paraffin per day in 2003, this number declined to 1100 barrels oil equivalent per day in 2008 (United States Information Administration, 2009).

The Gokwe areas is the area with the lowest use of paraffin lanterns (figure 4.2.2), table 4.3.1 shows the reason behind this phenomena. Average travel distance to buy paraffin is much higher in Gokwe (44Km) compared to the other regions. The average price of paraffin fluctuates between $1.13 in Mt Darwin up to $1.61 dollar in Mutasa.

These paraffin figures demonstrate that households spend money on lighting. Households are used to do periodic payments to pay for their lighting systems. This information can be used for the set up and development of payment schemes.

	Mt Darwin	Mutasa	Gokwe	Mutoko	Tsholotsho	Total
% Of households buying paraffin	63%	93%	42%	93%	83%	75%
Paraffin bought every…..weeks	8.6	3.1	12.5	3.4	2.0	5.7
Average price of paraffin in liters	$1.13	$1.61	$1.18	$1.46	$1.29	$1.23
Average paraffin use per week (liters)	0.44	0.42	0.19	0.80	0.65	0.48
Average distance travelled to buy paraffin (km)	24.39	2.27	44.05	1.13	10.45	24.45

Table 4.3.1: paraffin figures

4.4. Cell phone

More than 60 percent of the households have access to a cell phone (figure 4.4.1). Mutoko has by far the largest share almost 95 percent of the households has a cell phone. Gokwe lags behind with only 35 percent of the people having a cell phone. Almost 28 percent of the people that have a cell phone pay somebody else to charge their phone; this is mostly done at a local shop or business center. Charging cost varies between $0.2 and $1 per charge per phone. Households have told us that charging their phone is often difficult due to reason that they have to travel or negotiate with neighbors to get their phones charged. Households would like to have the possibility to charge their phone in their own house. Solar home charger will help households to save money on charging cost and become less dependent of neighbors and friends.

The last decade, there has been a fast growing of cellphone networks in developing countries. Fixed-line infrastructure has been skipped, and many countries leapfrogged directly into mobile technology, which made mobile telephony the dominating mode of communication in most developing countries nowadays. Mobile phones are an important step in increasing development, the main reasons behind this is that they offer basic benefits like mobility and security (Donner, 2006). Due to the fact that there is no reliability of physical infrastructure such as roads, phone wires and the electricity grid, mobile phones can be used in every possible location that has network coverage. Furthermore mobile phones in addition to voice communication make it possible to transfer data, for education, health, finance and other purposes. Mobile phones are affordable for large parts of the population and can therefore be used as a mechanism to ensure greater participation of the very poor (Rashid, 2009). All these reasons make the availability of mobile phones a step forward in to development.

In Zimbabwe the number of cell phone subscribes has tripled from 2 million at the end of 2008 to 6.9 million in 2010. Analysts expect the growth in mobile technology to continue, reaching more than 13 million subscribers by 2015. Prices of a mobile phone and a SIM- card have fallen drastically last years. Therefore they are now affordable for low income Zimbabweans in rural areas (Masimba Biriwasha, 2011).

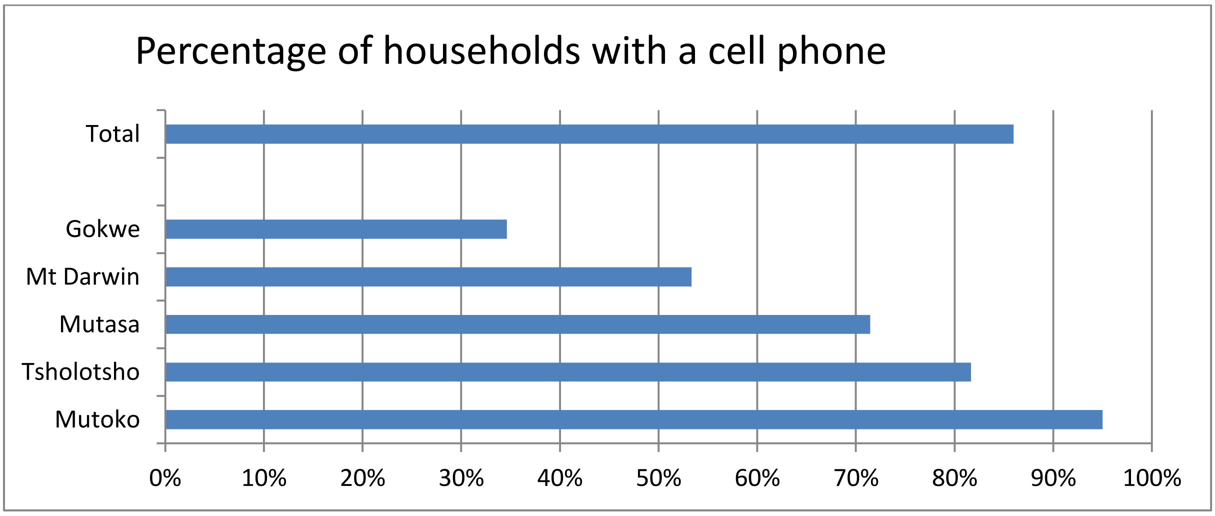
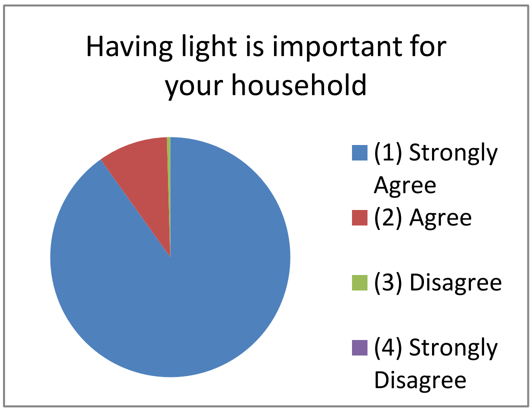


Figure 4.4.1: Percentage of households with a cell phone

4.5. Importance of light

Light is important for every household and it is also considered an important condition for their children education (Figure 4.5.1). Close to 100 percent of our households agree on these statements.



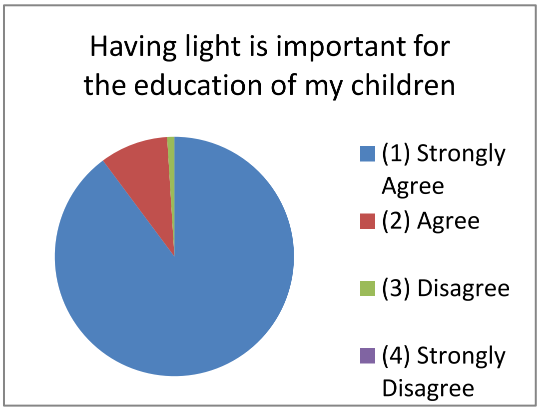


Figure 4.5.1: Importance of light

Around 50% of the household suffer from health problems caused by the currently used lighting systems (Figure 4.5.2). Worst is the situation in Mutoko and Tsholotsho, where 80 percent of the households experiences health problems due to the use of their lighting. Literature shows that insight fuel-based lighting like the use of a paraffin lantern leads to indoor air pollution and associated health risk (Mils 2000). Solar energy products do not have any health risk and therefore can contribute to the improvement of the health environment in rural households.

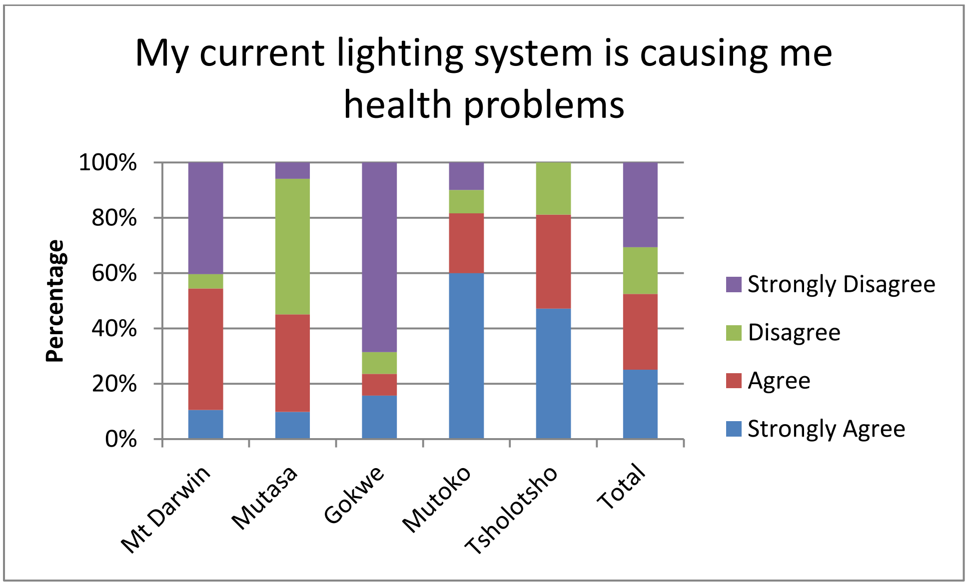


Figure 4.5.2: Lighting problems and health problems

All households in Gokwe and Mutasa feel safe in their homes after work, in Mutoko more than 80 percent of the household feels safe after dark (figure 4.5.3). Mt Darwin differs completely from the other three regions; in Mt Darwin more than 90 percent of household does not feel safe in their homes after dark. We have no explanation for these common unsafe feelings in the Mt Darwin area. It could be because of a mass grave that was found in March 2011 close to Mt Darwin, and the spread of rumours about those dangerous crimes. This reasoning is not based on any evidence but just speculations.

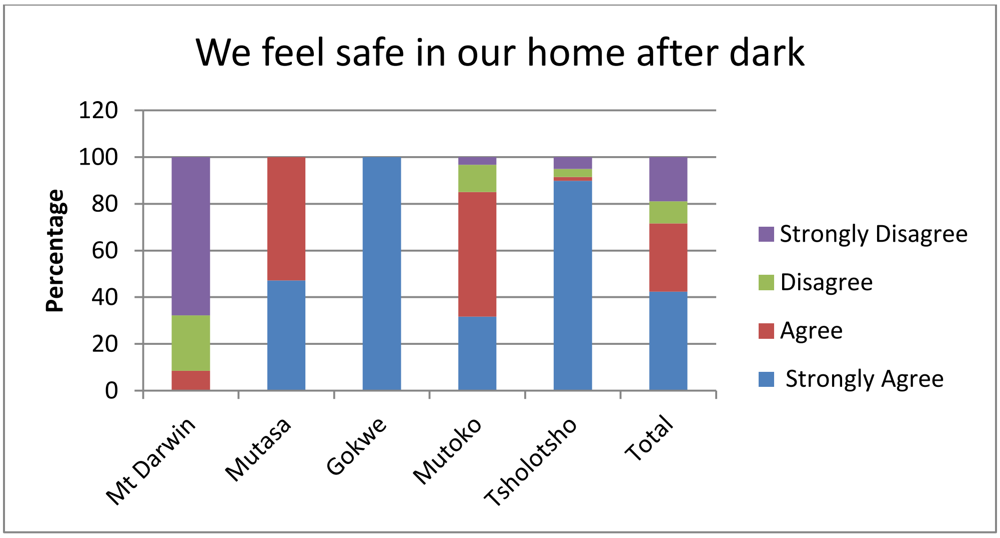


Figure 4.5.3: Feeling of safety after dark

4.6. Entertainment

Sixty percent of the households have a radio (figure 3.6.1). Mutoko differs from the other regions with an extremely high percentage of people having a radio. In Gokwe, Mutasa and Mt Darwin they have between 40 - 60 household with a radio on every 100 households.

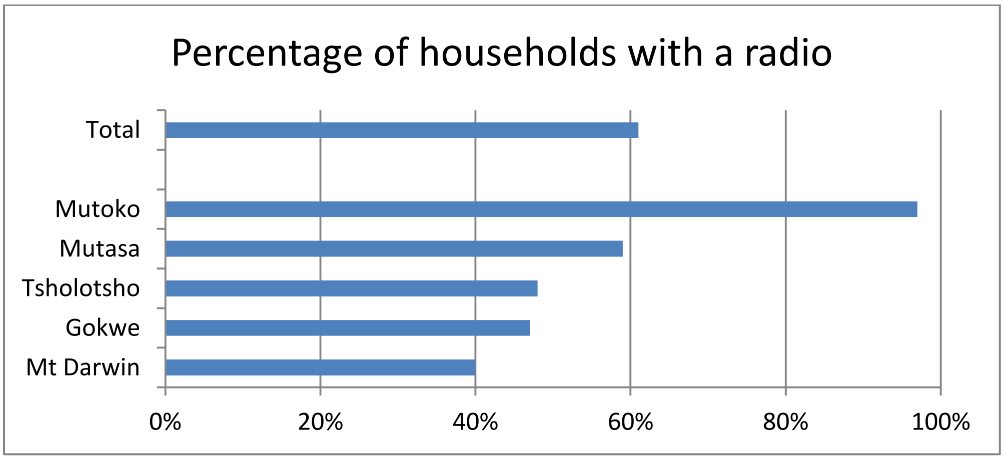


Figure 4.6.1: Percentage of households with radio

Televisions are scarce in the rural areas; by excluding the results from Mutoko only 20 percent of the households have a television. Mutoko shows different picture with 60 percent of the households having a television (figure 4.6.2).

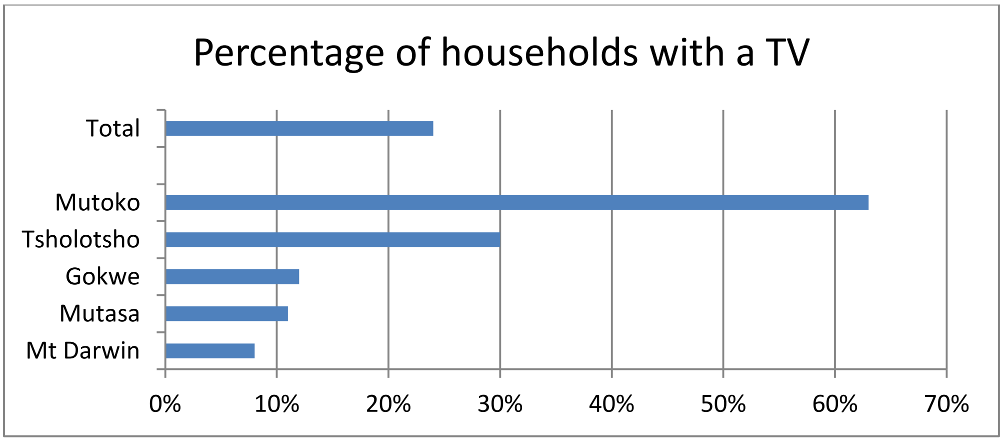


Figure 4.6.2: Percentage of households with a TV

Most households (42%) use a car battery or ordinary batteries to provide energy for their radio or TV. Twenty percent of the households with a radio or TV use solar energy to run it. This number is similar to the number (21.1%) found in an earlier study done by SNV on energy use in rural areas (SNV_HIVOS, 2011).

Except for lighting households also make use of electricity to power radio and TV. Therefore there is a need for more powerful energy supply. Small solar home systems are a good option to power these devices and replace batteries and generators.

4.7. Income

4.7.1. Monthly Income

There are no significant differences between average estimated and calculated income. Both are around $120 per household per month (table 3.7.1). The median estimated income is $80 (figure 3.7.1). The median calculated income is $84 (figure 3.7.2). Median income is approximately 35% lower as mean income. This difference is caused by outliers and extremes which greatly affect the mean. We study the income of average rural households not extremes and exceptions. Therefore the remainder of this section will use the median instead of the mean.

During the survey the enumerators first asked the households to estimate their monthly income, taking into account all possible income sources (estimated income). We expected that households would find it difficult to estimate their monthly income because most revenues are seasonal or vary strongly over the months and years. To overcome this problem we asked the households to specify all their different income sources per season, month or year (part 8 of survey). From these numbers total average monthly income is calculated (calculated income). The assumption that rural households find it difficult to estimate their own income is not reflected in the differences between calculated and estimated income. Those are not significantly different.

	N	Minimum	Maximum	Mean	Std. Deviation
Estimated monthly Income	228	$5	$900	$118.8	$119.8
Calculated monthly income	294	$0	$823	$120.7	$121.0

Table 4.7.1: Average monthly income

Income levels differ between the five research areas (figure 4.7.1 and 4.7.2). Mutoko and Gokwe are the regions with the highest income range in the selected study areas with an median income between $120 and $175. Tsholotsho and Mutasa districts represent the lower limits with average calculated income levels between $40 and $60 per month.

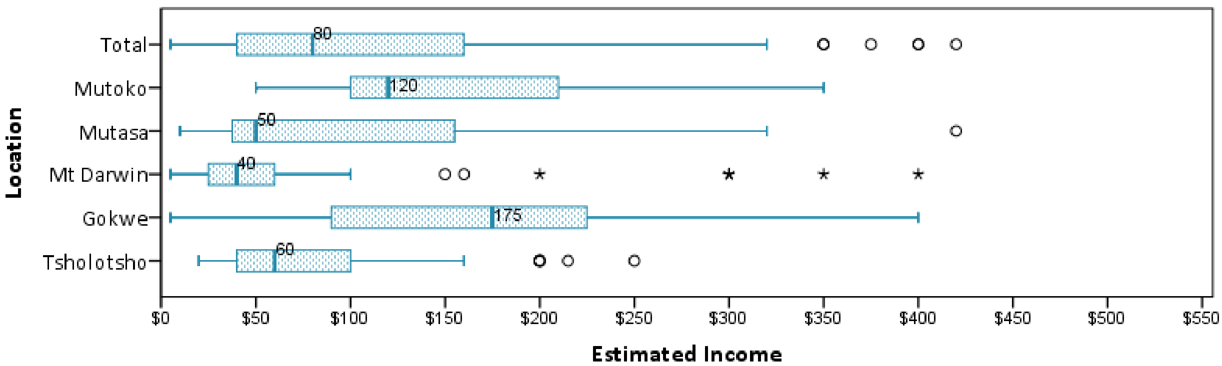


Figure 4.7.1: Estimated income per location

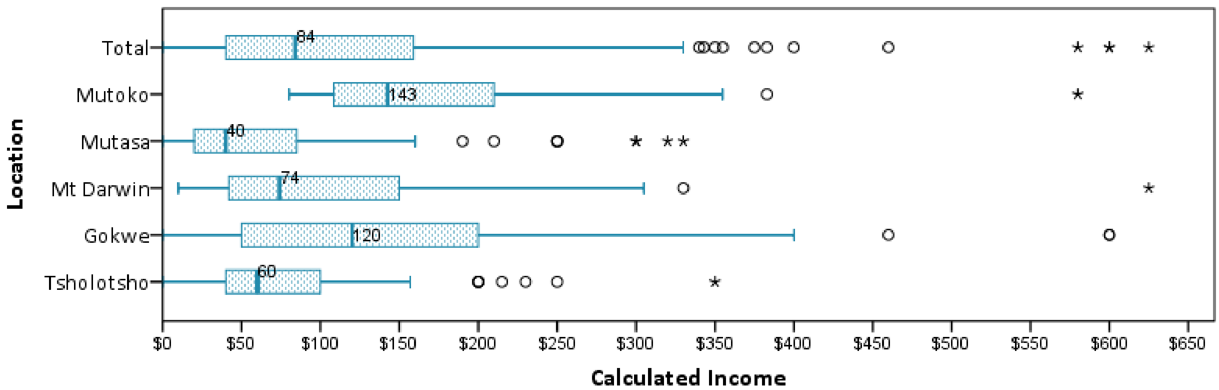
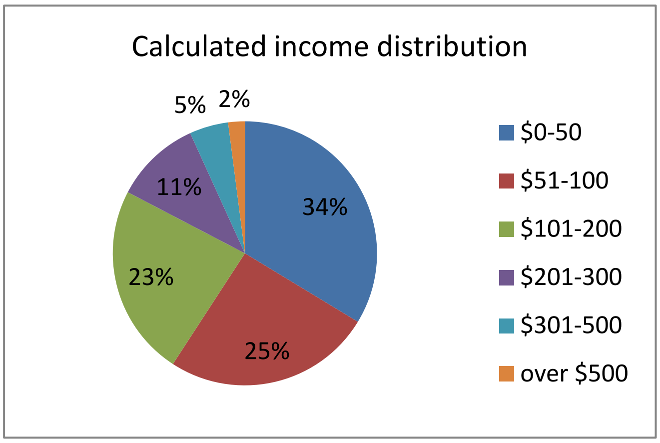


Figure 4.7.2: Calculated income per location

Comparing the incomes distribution with the various agricultural regions in figure 1.2.3 shows no pattern. We expected that income in farming region 1(the most furtile agricultural region) would be the highest, descending to the lower agricultural regions. However, in the selected sample this pattern is not perceptible.

4.7.2. Income distribution

Average income can be strongly influenced by high and low income outliers. To get a better understanding of income distribution among rural households the households are divided into six different income groups. As a result, it is also possible to compare the obtained data with data from the research done by SNV and HIVOS (SNV_HIVOS, 2011). Figure 4.7.3 shows income distribution of estimated and calculated income for our total sample.



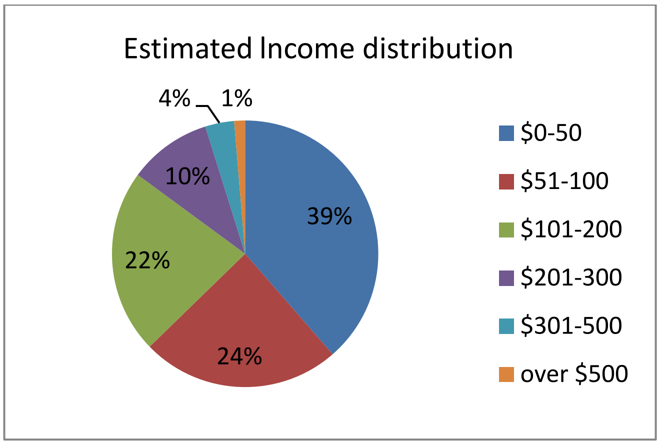


Figure 4.7.3: Income distribution

More than a third of the household earns less than $50 per month. Approximately half of the households earn between $50 and $200 every month and 15% of the households earn more than $200 every month (figure 3.7.3). The income distribution will be used later in the research in order to determine the capacity to pay of households.

Comparing our results with the data from the market survey by HIVOS and SNV in 2011 (figure 4.7.4) shows one important difference. This lower income group is significantly stronger represented in our household sample. This can be explained by the fact that this study has chosen to not represent the entire rural population. This study focuses on households in the remote areas away from the electricity grid and main road. In general income levels are lower in the more remote areas.

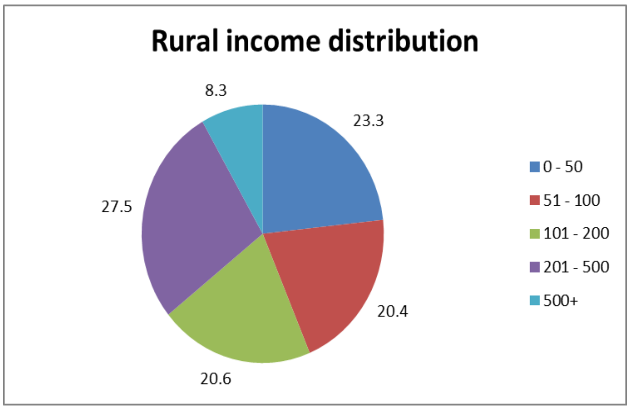


Figure 4.7.4: Rural income distribution (SNV_HIVOS, 2011)

4.8. Current solar energy use

After eliminating the duplicate data we see that 21 percent of the households have a solar product on the moment.

None of the households studied have access to the electricity grid, but already some of the households have solar products. The first market survey on current energy use shows that on the moment 10 percent of the households use solar energy for lighting purposes and 18 percent uses solar energy for entertainment purposes (ILO_SNV, 2012). We have no information about the quality or the price of the products they use on the moment. But the existence of solar products on the moment proves that rural households are already starting to get into solar products. The market is starting up and first products are sold to this market, rural households have knowledge of the existence of solar products and that they see it as a possibility to supply in their electricity consumption.

4.9. Overview results

The lighting system in rural Zimbabwe is average used for 200 minutes (3.3 hours) per household per day. Paraffin based systems are by far the most used lighting systems, more than 80% of the households uses a paraffin based system to light their house. On average they use 0.44 liter of paraffin every week with a mean price of $1.23 per liter. Torch light (34%), candles (24%) and wood fires (31%) are also frequently used for lighting. Solar is used by 10% of the households for their lighting consumption. Besides running lighting systems energy is used to charge cell phones and run radios and televisions. Over 60 % of the households have a cell phone. A quarter of this group pays between $0.2 and $1 each time to charge their phone. Sixty percent of the households own a radio. Televisions are scarce in the rural areas; by excluding the results from Mutoko with 60 percent, only 10 percent of the households own a television. Car batteries are the most important power supply for radio and TV (25%). Twenty-one percent of the households that own a radio or TV use a solar panel to run it.

Light is important for 100% of the households and it is also considered an important condition for their children education. Around 50% of the households indicated that they suffer from health problems caused by the currently used lighting system. In Mt Darwin more than 90 percent of household does not feel safe in their homes after dark

Average household income is $120 per month with half of the households earning between $50 and $200.

Households in rural areas use mainly paraffin based systems to light their houses. Money and time are spent to travel to shops and purchase paraffin. Replacing these paraffin based systems for a solar lighting system will save time (travel time) and money (to purchase paraffin). This time and money can be used to invest in their production capacity and thereby help them to further development.

Fifty percent of the households suffer from health problems caused by the paraffin light systems. This is because indoor burning of fossil fuels leads to a decrease of air quality. The use of solar products instead of paraffin lighting will solve the problems of poor air quality. A healthier rural population will have more opportunities to develop their current way of living through use of clean and renewable energy technologies for lighting.

People have problems with charging their phones because the absence of a reliable charging system. They have to go to the shops or neighbors to charge their phones. This process cost them money and time. Small solar home systems will give households the opportunity to charge their phones in their own time and in their own house. This will make people more flexible and will increase their communication abilities.

Solar home systems will make people less dependent on the environmental unfriendly car batteries and generators that are now used to power radios and TV's. The erection of solar home systems will also be dependent on readily available service delivery for installations and maintenance to reduce costs on depending on the services provided from the towns and cities.

Figure 4.9.1: Conducting surveys in Gokwe area (photo by Koen van Kuijk)

5. Results Contingent Valuation

5.1. Willingness to pay

5.1.1. Introduction

WTP for the three different products is displayed using a box plot. The box in a box plot represents half of the sample data. The median is the middle of the data distribution and is used to represent the data. The median is used instead of average to not overvalue the extremes and outliers of the data. Minimum and maximum data values are given by the end of the whiskers. The dots and start represent respectively outliers (dots) and extreme values (stars).

5.1.2. WTP Solar lantern

Households are WTP $19 to purchase a solar lantern. WTP ranges from $2 up to $60. Households in Gokwe are willing to pay the most with a median of $30. Tsholotsho has the lowest WTP of $9 (figure 5.1.1). Reason behind spatial difference in WTP for solar lanterns could be caused by income disparities or differences in current paraffin prices. The price of a solar lantern is approximately $10; the results show that the largest part of the households is willing to pay this amount to purchase a solar lantern.

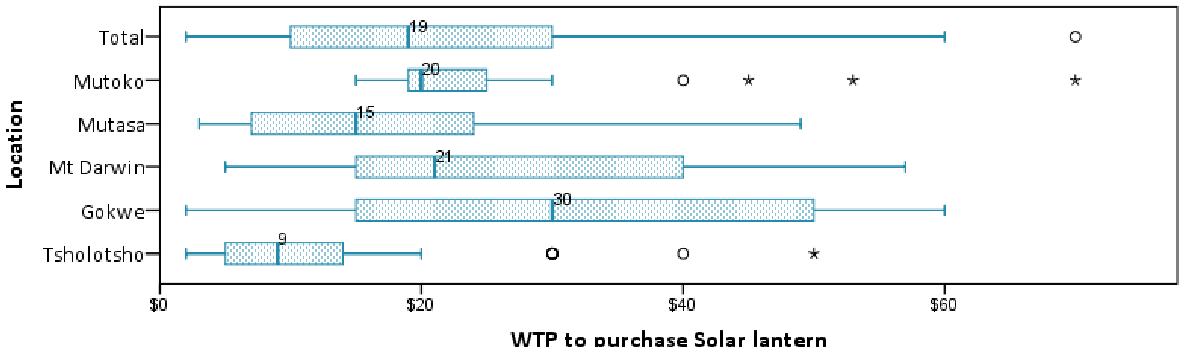


Figure 5.1.1: WTP to purchase solar lantern

Monthly WTP to rent to buy a solar lantern is $5 per month (figure 5.1.2). There is not much spatial variation throughout the country. Households are WTP $5 every month to guarantee the availability of one solar lantern. Monthly WTP for rent to buy is a 26% of the WTP to purchase a solar lantern. It would cost 4 months to cover WTP to purchase with the WTP for rent to buy. It indicates that households are WTP $5 to have one light in their house.

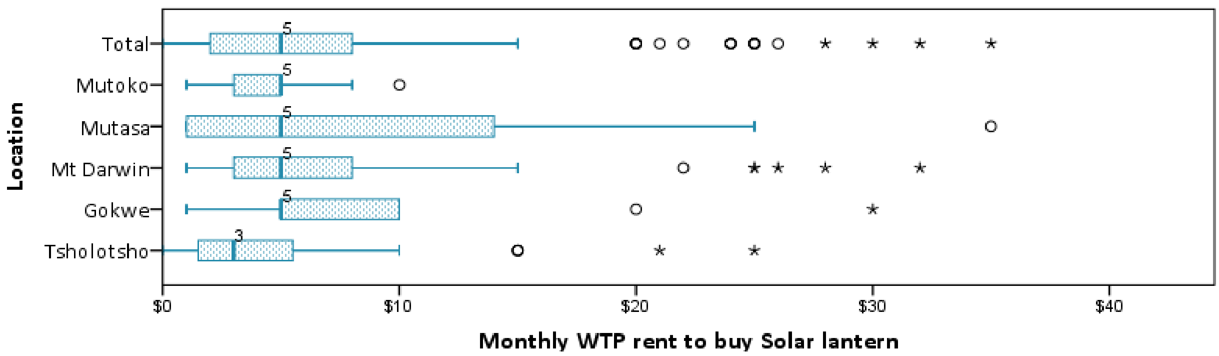


Figure 5.1.2: WTP rent to buy solar lantern

5.1.3. WTP Solar charger

Households are WTP $34 to purchase a solar charger. WTP ranges from $3 up to $90. Households in Gokwe are willing to pay the most with a median of $60. Mutasa has the lowest WTP of $20 (figure 5.1.3). The price of a solar lantern plus additional cell phone charger is approximately $25. This means that well over 50% of the households is willing to pay enough to purchase a solar lantern plus charger.

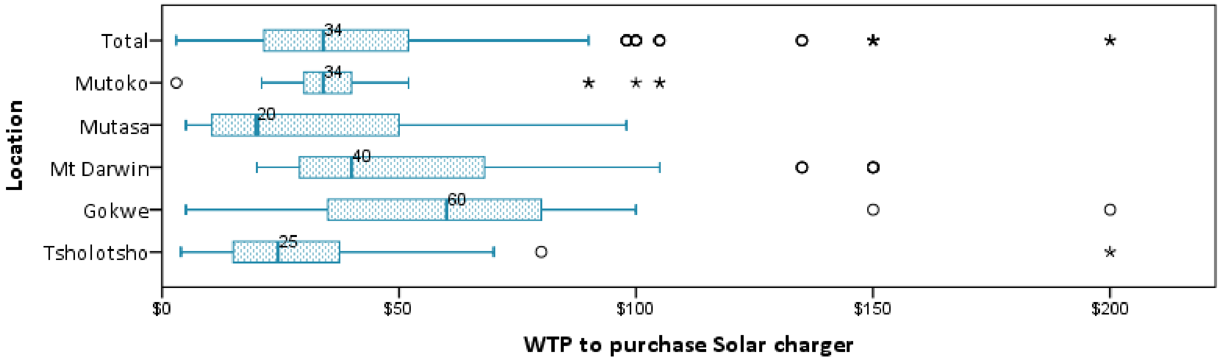


Figure 5.1.3: WTP to purchase solar charger

Monthly WTP to rent to buy a solar charger is $9 per month (figure 5.1.4). Monthly WTP for rent to buy is a 26% of the WTP to purchase a solar charger. Four months are needed to cover the WTP purchase price the rent to buy scheme.

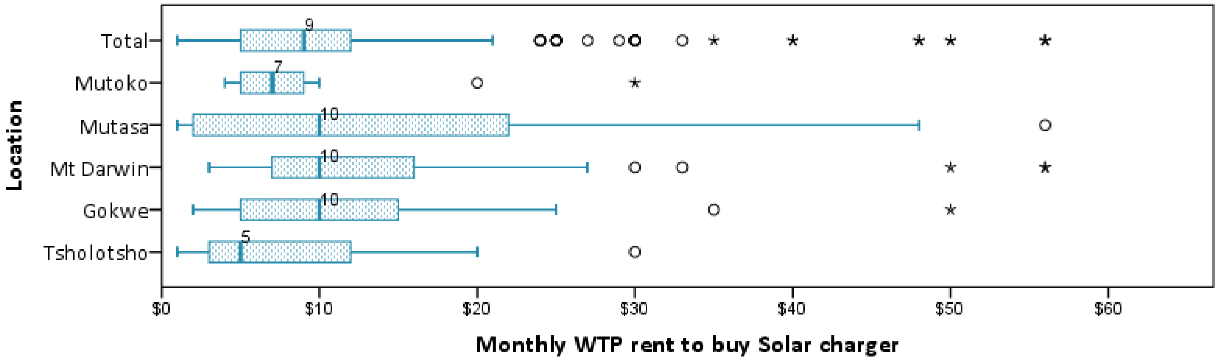


Figure 5.1.4: WTP rent to buy solar charger

5.1.4. WTP Small solar home system

Households are WTP $150 to purchase a small solar home system. WTP ranges from $2 up to $300. Households in Mutoko are willing to pay the most with a median of $250. Mutasa has the lowest WTP of $63 (figure 5.1.5).

WTP prices to purchase a small solar system are only 25 % of the actual price of approximately $500. Only one percent of the households is willing to pay this amount to purchase a small solar home system. This means that households WTP for small solar home systems is not high enough for purchase. There is not much market potential for the selling of solar systems.

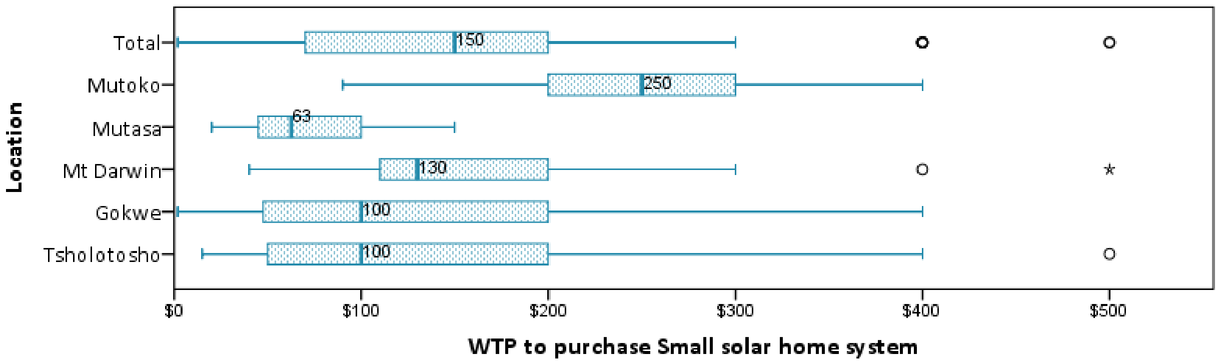


Figure 5.1.5: WTP to purchase small solar home system

Monthly WTP to rent to buy a small solar home system is $20 per month (figure 5.1.6). Monthly WTP for rent to buy is a 13% of the WTP to purchase a small solar home system. This means it would take households roughly 25 months to pay off a solar home system of $500. A two year payment scheme program is needed to sell solar home systems to rural households in Zimbabwe.

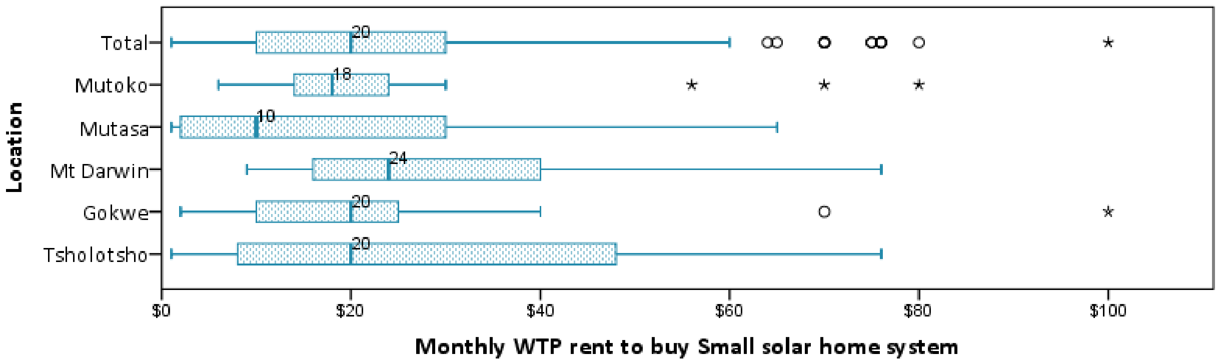


Figure 5.1.6: WTP rent to buy small solar home system

5.2. Distribution willingness to pay

5.2.1. Purchasing solar products

To better understand the distribution of WTP among households, we have displayed the distribution of WTP in figure 5.2.1 and figure 5.2.2. WTP is hereby divided into seven categories.

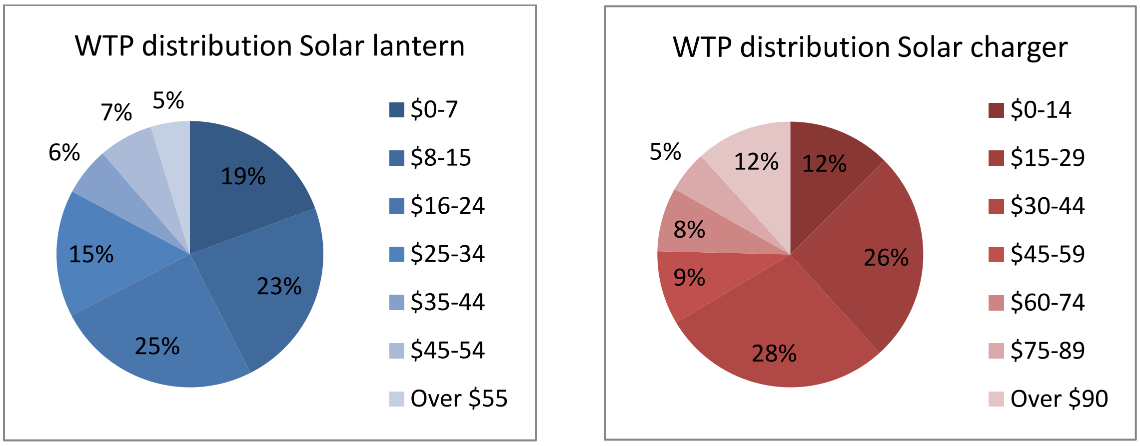


Figure 5.2.1: WTP distribution solar Lantern and solar charger

The data on WTP for a solar lantern and a solar charger is not normally distributed but skewed towards the lower values. It shows that 63% of the households is willing to pay an amount between $8 and $34 to purchase a solar lantern. A fifth of the households is not willing to pay more than $7 to purchase a solar lantern.

Two third of the household is willing to pay an amount between $15 and $59 to purchase a solar lantern + cellphone charger. Even 12% of the households is willing to pay more than $90 for a solar lantern + cellphone charger

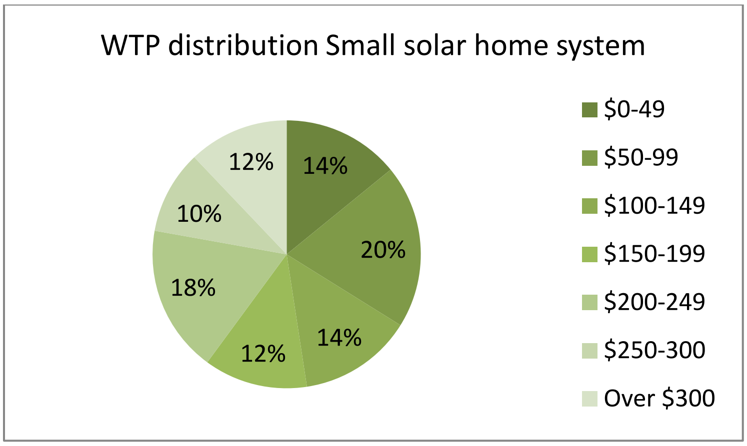


Figure 5.2.2: WTP distribution product 3

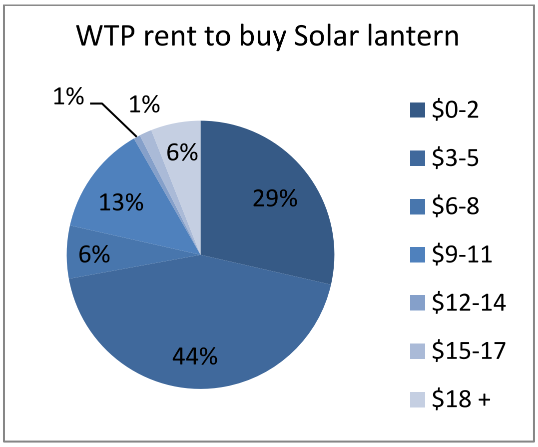
WTP for a small solar home system is not normally distributed; it is a more equal distribution over the 7 categories. This means a major division on the WTP for product 3. It might also indicate that the selected households find it difficult to value this product, which has led to large difference in WTP. The equal distribution along the categories explains the high standard deviation. Figure 4.2.2 shows that 66% of the household is willing to pay more than $100 to purchase a small solar home system.

5.2.2. Rent to buy

The distribution of WTP for rent to buy is interested for companies that would like to set up payment schemes for solar products. Results are presented in figure 4.2.3 and 4.2.4. These figures give the distribution of the willingness to pay for rent to buy schemes. This section is interesting because earlier research showed that people are not willing or able to pay for solar products at once.

Almost half of the households (44%) is willing to pay between $3 and $5 every month to rent to buy a solar lantern. A lease system for rent to buy should work with a payment scheme charging between $3 and $5 per month.

A quarter of the households is willing to pay between $9 and $11 every month to rent to buy a solar charger (Figure 5.2.3). Households are willing to pay an extra $6 per month to upgrade their solar lantern with a solar charger. Households value the extra of a solar charger higher than the actual availability of a light.



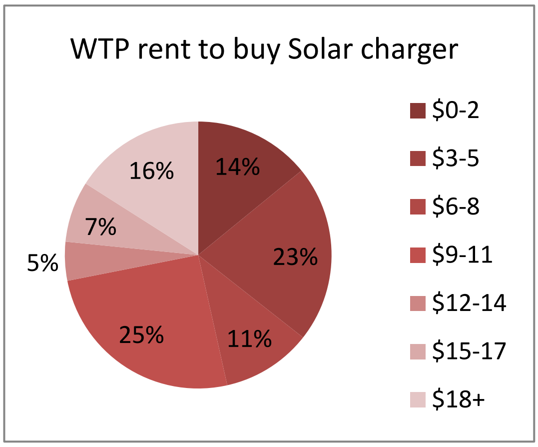


Figure 5.2.3: WTP distribution rent to buy solar lantern and solar charger

A third (31%) of the household is willing to pay an amount higher than $30 every month to rent to buy a small solar home system (figure 5.2.4).

In comparison on the moment households spend approximately $29 per month for lighting and entertainment purposes (SNV_HIVOS, 2011).

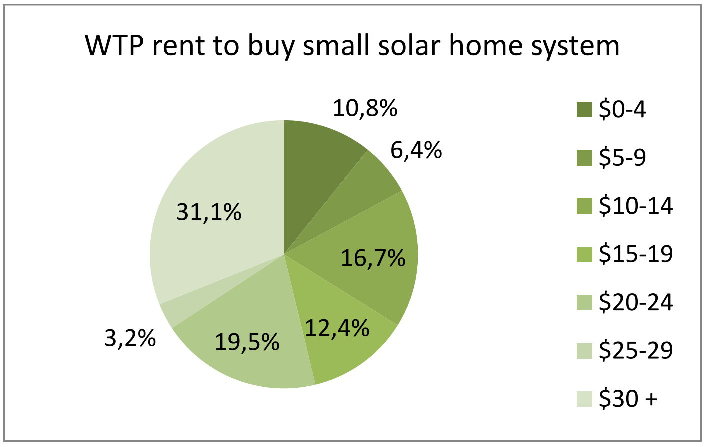


Figure 5.2.4: WTP distribution rent to buy small solar home system

5.3. Statistical analyses

5.3.1. Pearson correlation matrix

Table 5.3.1 shows the significant Pearson correlations between the solar products and the chosen variables.

Pearson's correlation matrix							
	People in household	Kids attending school	Minutes using lighting	Distance grid	Estimated income	Calculated income	Expenditures
WTP solar lantern	-0.049	-0.126*	-0.096	0.261**	0.332**	0.365**	0.038
WTP solar charger	-0.042	-0.092	-0.113	0.268**	0.349**	0.347**	0.019
WTP solar home system	-0.015	0.015	0.227**	-0.055	0.345**	0.346**	0.106
WTP rent to buy lantern	-0.066	-0.076	-0.102	0.128*	0.214**	0.191**	0.061
WTP rent to buy charger	-0.094	-0.107	-0.146*	0.244**	0.281**	0.224**	0.107
WTP rent to buy home system	-0.029	-0.015	-0.108	0.170*	0.151*	0.083	-0.031
*Correlation is significant at the 0.01 level (2-tailed) **							
Correlation is significant at the 0.05 level (2-tailed) *							

Table 5.3.1: Correlation matrix

The variables expenditures and people in a household have no significant correlation with WTP for one of the three products, or with the WTP for rent to buy.

WTP for products 1, 2 and 3 are positively correlated with estimated and calculated income ($r > .30$, medium effect), and significant at the 0.01 level. Higher income households have higher WTP for solar products. This is expected because a higher income means more available money to spend on consumption goods. Estimated income and calculated income are also positively correlated with WTP of for rent to buy solar products, correlation is weaker and in the case of a small solar home system not significant. Income is the most important factor when households purchase a solar product and therefore knowledge on income patterns is important for future research and policies. Understanding of income patterns could help young entrepreneurs in the development of their business plans and strategy in household marketing.

The WTP of products 1 and 2 are also positively correlated by distance to the grid ($r = 0.29$), $p = 0.00$). Households further away from the grid are willing to pay more for solar lanterns. In my opinion this correlation is caused by the hope of grid extensions. Households who live next to the grid will most likely wait for a connection to the grid. Therefore they are less concerned with alternative energy supply.

Contrary to expectations there is no significant correlation between Minutes using the lighting system and the WTP for a solar lantern and solar charger. WTP for small solar home systems is positively correlated to the minutes using the lighting system ($r=0.221$, small effect). Households with a higher demand for lighting have a higher WTP for a small solar home system. Current lighting use influences the WTP of the more advanced systems. This might be because the more simple products are not interested anymore for these households because light revenues are not high enough.

5.3.2. Multi linear regression analysis

The variables calculated income, distance to the grid, minutes using the lighting, expenditures, kids attending school and number of people in a household are now used in a multi-linear regression analysis. Table 5.3.2 shows the regression models of the WTP for the three different products.

WTP = f {Income, expenditures, number of minutes using the lighting system, distance to grid, number of people living in a household, number of kids attending school}

WTP for a solar lantern is positively influenced by the variables income and distance to the grid. The number of minutes using the lighting system has a negative influence on WTP, but this coefficient is not significant. The R-squared is 0.188, meaning that approximately 18.8% of the variability of the WTP for a solar lantern is accounted for by the variables in the model.

Regression WTP			
Variable	**WTP Solar lantern**	**WTP Solar charger**	**WTP Solar home system**
Constant	12.634***	24.284***	73.663***
Income	0.044***	0.090***	0.266***
Distance to grid	0.355***	0.837***	0.273
Minutes using lighting system	-0.003	-0.005	0.169***
Expenditures	0.001	-0.002	0.027
Kids attending school	-1.437*	-1.891	-3.533
Nr of people in household	0.612	0.864	0.406
N	273	256	248
R^2	0.188	0.175	0.166
R^2 (adjusted)	0.167	0.153	0.142
** Significant at 10% level ** significant at 5% level *** significant at 1% level*			

Table 5.3.2: Multi-linear regression WTP

The third column shows the regression analysis for a solar lantern with cell-phone charger. The results are similar to the results of the solar lantern. But in this case WTP is even more influenced by the distance to the grid. Minutes using the lighting system have again a negative influence on WTP, but it is not significantly negative.

The fourth column shows the regression model for a small solar home system. The R-squared is 0.158. WTP is stronger influenced by calculated income as it was with product 1 and 2. Now we also see a significant influence of the number of minutes using the lighting system on WTP. Households with a higher demand for lighting have a higher WTP for a small solar home system.

WTP for the solar products is as expected influenced by income. The more expensive a product is the more its WTP is influenced by income. Interested to see is that a higher demand for lighting is only influencing WTP for the most advanced system, small solar home system. Reason behind this is probably that a solar lantern is to simplified to meet the high demand of these households.

5.4. Overview results WTP

Households are WTP $19 to purchase a solar lantern. The approximately actual price of $10 for a solar lantern makes the rural areas in Zimbabwe suitable as a market for solar lanterns. WTP of over 75% of the households is higher as actual purchase cost. Monthly households are willing to pay $5 to rent to buy a solar lantern; this is 25% of WTP to purchase the lantern.

Households are WTP $34 to purchase a solar lantern plus additional charger. Over 50% of the households are WTP more than the $25 price that is usually paid for a solar charger. Monthly households are WTP $9 to rent to buy the solar charger. Households need a three month payment scheme to cover current purchase price.

WTP for a small solar home system is $150. WTP is too small to cover the current cost of a small solar home system of approximately $500. This means there is no market potential for the selling of small solar home systems. Monthly households are willing to pay $24 to rent to buy a small solar home system. It would take households roughly 25 months to pay off a solar home system of $500. A two year payment scheme program is needed to sell solar home systems to rural households in Zimbabwe. This $24 per month is a valid number for household to spend on electricity because it corresponds to the amount of money household spend on the moment for lighting and entertainment (average of $29 per month). This leads to the following market plan; offer small solar home systems to households that will supply them with their lighting and entertainment electricity demand. Charge every household up to $25 per month will lead to yearly revenue of $300 per household. The average income of a household is $120 per month, $25 means they will spend a fifth of their income on lighting and entertainment. Earlier research showed that many households in developing countries spend up to 30 percent of their income on fuel based lighting systems (Mills, 2000).

Statistical analysis showed that WTP for all the three solar products is positively influenced by income. The solar lantern and solar charger WTP are also affected by the distance to the grid. WTP for a small solar home system is significantly higher when households make more use of their lighting system. Entrepreneurs that would like to enter the rural market for solar products should focus on households with a higher income and a high demand for lighting.

6. Results Market Potential

6.1. Introduction

The factors market size, WTP and capacity to pay are used to compute economical market potential (figure 6.1.1).

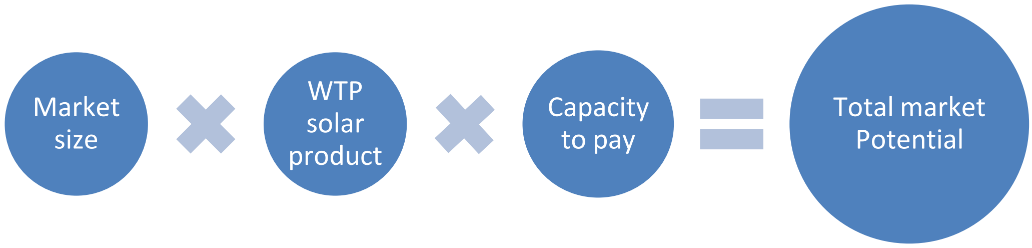


Figure 6.1.1: Calculation market potential

6.2. Market size

More than 1.5 million households in Zimbabwe (77%) live without access to electricity. Electrification rates are highest around the cities Harare and Bulawayo. In absolute numbers most households without access to electricity live in the north and east parts of Zimbabwe. The west side of the country is less densely populated and therefore a smaller potential market for solar products.

Potential buyers of solar product are the households without access to electricity. Figure 6.2.1 shows electrification rates in Zimbabwe. The left side shows the percentage of the households without access to electricity. The right side of figure 6.2.1 shows the absolute number of households without access to electricity per district.

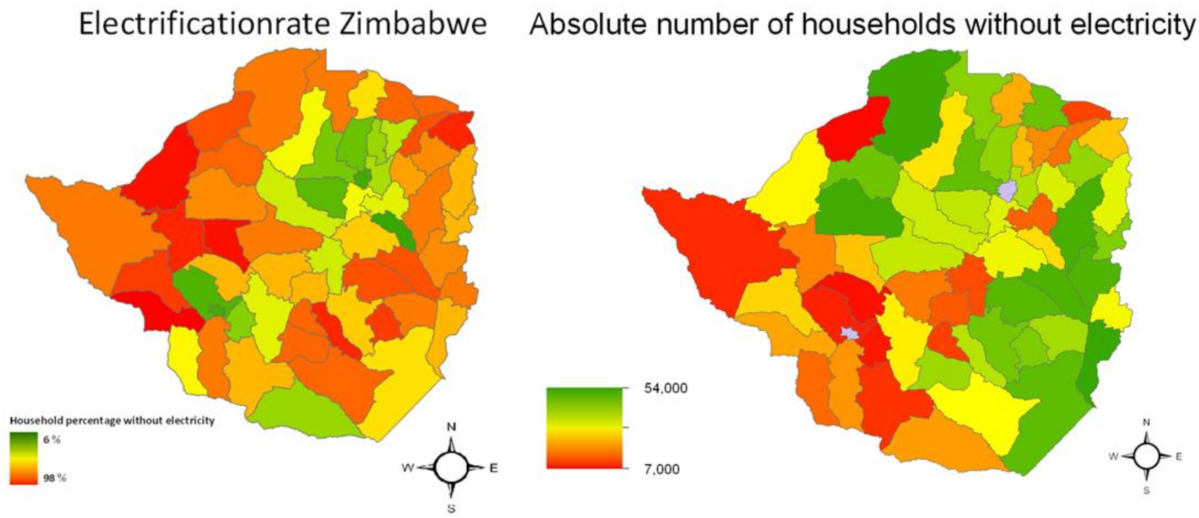


Figure 6.2.1: Electrification rate Zimbabwe

The 5 districts where market surveys are conducted are used as reference areas because WTP figures are known here. Figure 6.2.2 shows that market size within the five districts is between 20 thousand and 37 thousand households.

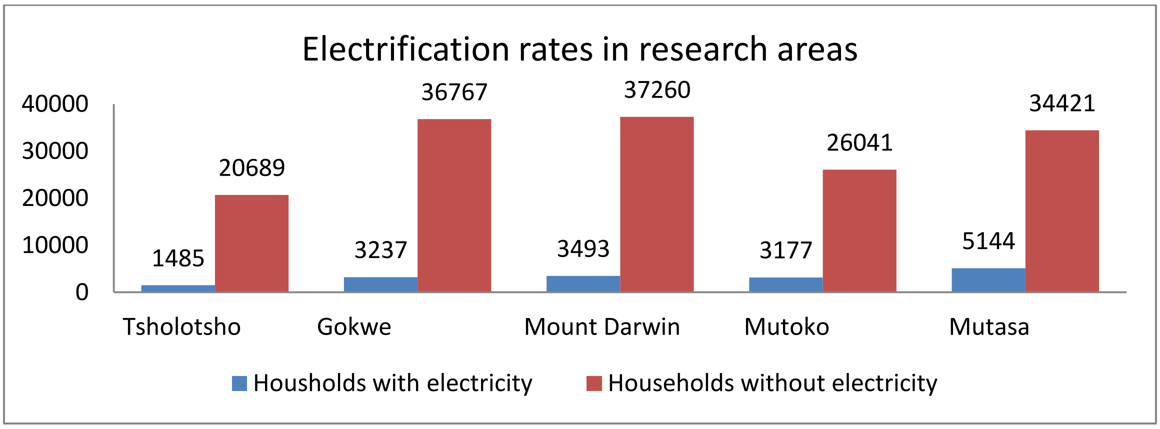


Figure 6.2.2: Electrification rates research areas

6.3. Capacity to pay

WTP for solar products is limited by the income of a household. In this research we exclude households as able to pay when they earn less than 4 times the cost of the solar product. We assume that households are maximum capable to spend 25% of their income in ones on a solar product. Actual market prices for solar products are described in paragraph 1.4.4. The costs for a solar lantern are approximately $10, for a solar lantern plus additional cell phone charger costs are $25 and for a small solar home system you pay approximately $500. Therefore households should earn above $40 to purchase a solar lantern, above $100 to purchase a solar lantern plus additional charger and over $2000 to be able to buy a small solar home system. Table 6.3.1 shows the capacity to pay of households in Zimbabwe and especially the research areas.

District	Income over $40 Capable to buy solar lantern	Income above $100 Capable to buy solar charger	Income over $2000 Capable to buy small solar home system
Tsholotsho	77%	30%	0%
Gokwe	92%	62%	0%
Mt Darwin	84%	40%	0%
Mutoko	100%	78%	0%
Mutasa	65%	23%	0%
Total	84%	47%	0%

Table 6.3.1: Capacity to pay of household in Zimbabwe

Assuming that households need to earn 4 times the purchase price of a product as a monthly income to be capable enough to pay. It can be concluded that 78% of rural households is able to purchase a solar lantern. 47% is able to purchase a solar lantern plus additional charger. None of the households earn above $1000 per month, which means none of them is capable to purchase a solar home system in ones.

6.4. Market Potential

To calculate total economical market value of rural Zimbabwe, market size is multiplied with WTP and capacity to pay for solar products. Results are presented in table 6.4.1-6.4.3.

District	Households without electricity	WTP solar lantern	Capacity to pay	Market potential
Tsholotsho	20689	$11	77%	$175,236
Gokwe	36767	$33	92%	$1,116,246
Mt Darwin	37260	$27	84%	$845,057
Mutoko	26041	$24	100%	$624,984
Mutasa	34421	$16	65%	$357,978
Research area	155178	$22	84%	$2,867,689
Zimbabwe	1536090	$22	84%	$28,386,943

Table 6.4.1: Market potential for the sale of solar lanterns in rural areas of Zimbabwe

- Total market potential for a solar lantern in our five research areas is $2.9 million.
- Rural households in Zimbabwe represent a market potential for solar lanterns of $28.4 million.

District	Households without electricity	WTP solar lantern + charger	Capacity to pay	Market potential
Tsholotsho	20689	$29	30%	$179,994
Gokwe	36767	$61	62%	$1,390,528
Mt Darwin	37260	$57	40%	$849,528
Mutoko	26041	$40	78%	$812,479
Mutasa	34421	$33	23%	$261,255
Research area	155178	$44	47%	$3,209,081
Zimbabwe	1536090	$44	47%	$31,766,341

Table 6.4.2; Market potential for the sale of solar lantern + charger in rural areas of Zimbabwe

- Total market potential for a solar lantern with charger in our five research areas is $3.2 million.
- Zimbabwe households represent a market potential for solar lanterns in combination with a charger of $31.8 million.

District	Households without electricity	WTP small solar home system	Capacity to pay	Market potential
Tsholotsho	20689	$135	0%	$0
Gokwe	36767	$125	0%	$0
Mt Darwin	37260	$157	0%	$0
Mutoko	26041	$232	0%	$0
Mutasa	34421	$74	0%	$0
Research area	155.178	$153	0%	$0
Zimbabwe	1536090	$153	0%	$0

Table 6.4.3: Market potential for the sale of small solar home systems in rural areas of Zimbabwe

- Households in rural Zimbabwe are not able to buy a small solar home system due to high purchase cost. Therefore market potential for a small solar home system is $0.

Market potential is only calculated for the purchase of solar products. Rent to buy schemes need to be developed to calculate market potential for monthly payment schemes. In rent to buy schemes revenues will be influenced by interest rates, collection cost and other risk factors.

6.5. Overview results market potential

Taking into account the factors market potential, capacity to pay and WTP can be concluded that there is a large potential market for the sale of solar lanterns and solar chargers. Total market potential for Zimbabwe of solar lanterns is estimated at $28.4 million. The total market potential for the sale of solar lanterns with an additional cell phone charger is estimated at $31.8 million.

There is no market potential for the sale of small solar home systems in rural Zimbabwe. Households are not capable to pay for these systems in ones. Therefore payment scheme mechanisms need to be developed to give households access to these systems.

Discussion and Conclusion

This research has studied the natural and economical potential for solar energy in rural Zimbabwe. This chapter will present the answers on the research question and the main conclusions. Furthermore this chapter will make recommendation for future academic research.

Conclusion

In the rural areas of Zimbabwe 81% of the households have no access to electricity. In a country with an abundance of sunlight available this has previously led to the conclusion that solar energy is a good option to increase the electrification rate of Zimbabwe. Nevertheless previous subsidy programs have been stranded due to several factors. One goal of the research is to study whether there are possibilities for a sustainable solar energy market in Zimbabwe that is not based on subsidies. Therefore the research question and sub questions of this report are:

What is the potential for solar energy in rural Zimbabwe; combining natural radiation potential and economical feasibility?

1. What is the spatial distribution of sun hours and solar irradiation throughout Zimbabwe?
2. What is the electricity production potential of solar PV in Zimbabwe?
3. What is the current state of energy use for lighting and entertainment in rural areas?
4. What is the willingness to pay for three different solar products? Distinguishing between WTP for purchase and for rent to buy scheme.
5. Is there a relation between the current energy use, income, household composition and WTP for solar products?
6. What is the economical market potential for solar energy in selected rural areas, linking WTP, capacity to pay, and market size?

The answers for this research questions and the conclusions drawn can be summarized as follows:

1. Zimbabwe has an annual average between 6.7 and 8.9 sunshine hours per day. The west gets the most sunshine, with averages up to 8.9 hours per day. The elevated east gets less sunshine as low as 6.7 hours per day. This difference in sunshine hours can be explained by the rainfall pattern throughout the country shown in figure 1.2.3. The fertile central and eastern parts of the country receive more rainfall which leads to a smaller amount of sun hours. The sparsely populated western part of the country receives more hours of sunshine than the denser populated east.

   Solar irradiance is between 1857 and 2257 kWh per square meter per year in Zimbabwe. The two different methods used to determine solar irradiance give two different outcomes. The angstrom method shows a less clear pattern and smaller absolute differences in solar irradiance (between 2257 and 2106 kWh/m²/year). PVGIS method has a clear north-south distribution of solar irradiance with larger absolute differences between the lowest (1857 kWh/m2/year) and the highest (2161 kWh/m²/year) irradiance levels.

2. Solar panels in Zimbabwe have an average electricity production of 359 kWh/m²/year. This means that when every household installs 1m² of solar PV this would lead to a total annual natural potential of 951mln kWh. An electricity power consumption of 10 billion kWh per year means that Zimbabwe needs 11m² of solar panels per household.

3. The lighting system in rural Zimbabwe is average used for 200 minutes (3.3 hours) per household per day. Paraffin based systems are by far the most used lighting systems, more than 80% of the households uses a paraffin based system to light their house. Torch light (34%), candles (24%) and wood fires (31%) are also frequently used for lighting. Solar energy products are used by 10% of the households for their lighting consumption. Besides providing power for lighting system's energy is used to charge cell phones and run radios and televisions. Car batteries are the most important power supply for radio and TV (25%). Twenty-one percent of the households that own a radio or TV use a solar panel to run it. Light is important for all households, it is also considered an important condition for their children's education. Around 50% of the households indicated that they suffer from health problems caused by the currently used lighting system.

   Replacing the current lighting systems by solar energy product will lead to an improvement in live quality and more time to further develop current situation. The money that is currently spent on paraffin can be used to invest in solar products, this will save households the time of travelling to buy products and also the cost for purchasing paraffin. Replacing current lighting systems for solar energy will also improve air quality and therefore contribute to a healthier population. Households furthermore have problems with charging their phones because the absence of a reliable charging system. They have to go to the shops or neighbors to charge their phones. This process costs them money and time. Small solar home systems will give households the opportunity to charge their phones in their own time and in their own house. This will make people more flexible and will increase their communication abilities.

4. Households are WTP is $19 to purchase a solar lantern. The approximately actual price of $10 for a solar lantern makes the rural areas in Zimbabwe suitable as a market for solar lanterns. WTP of over 75% of the households is higher as the actual purchase cost. Monthly households are willing to pay $5 to rent to buy a solar lantern; this is 25% of WTP to purchase the lantern.

   Households are WTP $34 to purchase a solar lantern plus additional charger. Over 50% of the households have a WTP more than the $25 price that is usually paid for a solar charger. Monthly households are WTP $9 to rent to buy the solar charger. Households need a three month payment scheme to cover current purchase price.

   WTP for a small solar home system is $150. WTP is too small to cover the current cost of a small solar home system of approximately $500. This indicates there is no market potential for the selling of small solar home systems. Monthly households are willing to pay $24 to rent to buy a small solar home system. It would take households roughly 25 months to pay off a solar home system of $500. A two year payment scheme program is needed to sell solar home systems to rural households in Zimbabwe. This $24 per month is a valid number for household to spend on electricity because it corresponds to the amount of money household spend at the moment for lighting and entertainment (average of $29 per month). Earlier research showed that many households in developing countries spend up to 30 percent of their income on fuel based lighting systems (Mills, 2000).

5. Statistical analysis showed that WTP for all the three solar products is significantly influenced by income. The solar lantern and solar charger WTP is also affected by the distance to the grid. WTP for a small solar home system is significantly higher when households make more use of their lighting system. Entrepreneurs that would like to enter the rural market for solar products should focus on household with a higher income and a high demand for lighting.

6. Taking into account the factors market potential, capacity to pay and WTP can be concluded that there is a large potential market for the sale of solar lanterns and solar chargers. Total market potential for Zimbabwe of solar lanterns is estimated at $28.4 million. The total market potential for the sale of solar lanterns with an additional cell phone charger is estimated at $31.8 million.

   On the moment there is no market potential for the sale of small solar home systems in rural Zimbabwe. Households are not capable to pay for these systems in ones. Therefore payment scheme mechanisms need to be developed to give households access to these systems.

The climate of Zimbabwe can be seen as very suitable for the installation of solar PV, many sunshine hours and high radiation levels lead to an electricity potential of 359 kWh/m²/year. This is twice the potential of solar energy per m² in the Netherlands. However the miss match between demand and supply (demand at night and supply by day) is a serious issue that needs to be solved before total potential can be utilized.

The economical potential for solar energy is high for lower cost products like solar lanterns and charger. Rural households make use of the lighting system and entertainment systems frequently. Their income and WTP is high enough to invest in small solar energy products like solar lanterns and solar chargers. The market potential for these products is high, and can therefore be seen as a good investment opportunity for local entrepreneurs.

Small solar home systems are too expensive and not within the capacity to pay of rural households in Zimbabwe. The development of payment scheme is necessary to further investigate investment in this solar option.

Discussion

This study has made certain assumptions in determining total economical potential. Economical potential is based on market size , WTP and capacity to pay. Other possible important factors like cultural acceptance, regulations and laws are not taken into account. Leaving out these factors leads to a more simplified image, but it does not mean that is less useful. Income, market size and willingness to pay for a product are the most important factors that influence market potential. The other factors can be seen as preconditions that can be influenced by governmental policies.

The contingent valuation method in this study does not examines the WTP for alternative energy options and possibilities. The households state only their WTP for solar products. It would have been interested to compare their WTP for solar with their WTP for other energy options like WTP for grid access, or WTP for access to a generator. This is not done because this research focuses on solar energy, and possibilities for solar entrepreneurs to enter this marktet. There is a need and opportunity for future research to further examine the choices of households between different energy sources and alternatives. The choice modelling method could be one of the instruments to further investigate the future decisions of Zimbabwean households.

The two surveys done where administered to 288 different households by field officers from the 'Training for Rural Economic Empowerment' ILO program. This was after an initial process in each district with the field officers and author to test the survey and do trainings on the data collection methodology and WTP approach. In total 10 enumerators were involved in the process of data collection. This high number of enumerators could have led to different interpretation of the asked questions and given answers by the enumerators. This interpretation and understanding was made more difficult due to the language differences. The enumerators had to translate the question from English in to Shona and the answers back from Shona toward English. This could have also led to some data errors. However to minimize these problem, intensive training was done and the author went into the field with all enumerators to make sure that they interpreted the questions as good as possible.

The locations (villages) for the surveys were pre-selected by ILO on the basis of the availability of field officers and a cooperative attitude of the administration. In the field households must meet two conditions to be included in the research; no access to electricity and living away from the main road. These conditions were set to make sure households live in their rural areas and have no access to electricity. For further research it might be interested to also examine WTP of peri-urban and Urban households with and without access to the grid.

Overall solar energy can be seen as a very interesting option in the future energy supply of Zimbabwe. Natural circumstances are suitable (Average electricity potential of 359 kWh/m²/year) to support solar investments. Households have a need for energy access and are willing to pay enough to create a sustainable solar product market.

Recommendations

Current income and WTP levels in Zimbabwe are not high enough to purchase small solar home systems. Therefore the development and further analysis of monthly payment schemes is necessary. Payment schemes could make more expensive systems available for rural households. These small solar home systems might be the cheapest option to give households access to modern energy. It could be an important step forward in increasing income and development for rural households in Zimbabwe. Further research is needed to find out what the possibilities are for payment schemes in rural Zimbabwe. Important factors that need to be studied are: interest levels, availability of funds and insurance options.

The miss match between demand and supply for solar energy(demand at night and supply by day) is a serious issue that needs to be solved to totally access the potential of solar energy. Research is needed in the development of long term vision on electricity production in Zimbabwe. Storage and distribution of electricity are two important factors that need to be examined to guarantee electricity access for the population of Zimbabwe in the future.

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APPENDIX I

Interviews Solar Companies

Client Report

Company: Solar shack/Clamore
Name: Tafi Chikwakwata
Date: 22 May 2012
Meeting: 1
Time of interview: 80 minutes
Tel: 0772716594
Email: info@clamorepower.com

Highlights

Solar shack is a retail outlet. Is a company that just sells solar products, there is no additional action. They focus on one product at a time and when this is done they move to the next product.

Clamore power is the technical part of the company. They install solar systems, and they do maintenance.

Clamore works together with DRI, they even share offices. DRI is a NGO that informs people on subjects like climate change and other environmental problems. Together they work on green warrior clubs → they go to schools and learn students about solar energy and clobal change, they try them to give a basic of knowledge and give them some easy skills. They try to get them enthusiastic and aware of solar and environmental issues. They the kids physicaaly informed and teached them some basic knowledges

They have offices in Harare, Kadoma and Gwekwe.

There product range is from simple lanterns till fully equipped solar home systems.

Lots of people miss the knowledge about products.

For example, many people choose to buy a cheap battery and replace it after a view months. Instead of buying a more expensive battery and use it for example 2 years. This causes environmental pollution, and makes it hard to sell sustainable products.

Thinks need to get bankable; this is the problem of the rural areas. Market is so huge; you cannot meet demand when it gets unlocked. But now there is the problem of finance. People don't have the ability to save money, and banks do not want to give credits.

New idea is TM bank stocking → bring you chicken to the bank and get money in return.

Seventy percent female is impossible. He now has 100 percent male staff. He tried to contract female staff, but it just did not worked out well. Education level is to low or work is too tough.

Association might be a good idea, but only when this is an independent organisation that is run by the government. Companies working together in this organisation will not work and only lead to fights and arguments. There are too many different ideas. This can only be managed by an independent governmental organisation. Standard association should be involved.

Is a need for working together with the government to speed thinks up and create long term sustainability?

Client Report

Company: Impact Solar Energy
Name: Chamu C. Muchenje
Date: 21 May 2012
Meeting: 1
Time of interview: 75 minutes
Tel +2634752245/6
Email:muchenjeconsult@gmail.com

Highlights

Impact Solar is in the solar energy business since 1991, the start of the GEF program. They first had two offices but they closed their Bulawayo office last year because there was nothing happening.

Muchenje believes that solar in rural areas is dying due to the fact of bad quality experience. People have no information about products and there is no monitoring on the quality and maintenance of products. There is a need for rural based installers. He also states that there is a big problem with inferior products entering the markets, destroying the work that is done by the good "companies". Cheap problems are one of the reasons why for him it is not possible to enter the rural markets.

Muchenje sees rural markets as a great potential, but on the moment it is not profitable to enter the markets. The markets are locked and he waits till they get unlocked. The costs are too high and there is not enough profit to be made. Upper class urban markets instead are highly profitable and are the main business area of impact solar.

He says we should not focus on the numbers (employment and people getting access to electricity) but he really wants sustainability. His proposal would be to empower a view companies that get some market advantages.

He likes the story of training young people, but he is sceptical about the 70 percent female part. He things this is challenge that is difficult to achieve.

On the moment impact solar is focussing on the high income markets. They sell mainly large solar home systems that require high qualified electricians. He was talking systems between 3 and 5 thousand dollars. They have one solar lantern available which would cost around $14 (Nokero).

Muchenje was involved in SEIAZ; he was member of the board. He believes in the concept of a solar industry association. And thinks it has the following benefits: Could be used for monitoring the market, market protection, access to funding, collaboration of companies, access to information and materials for members, and possibilities for training. During the times of the GEF project is was not possible to sustain the association by fees from the companies. Association was paid by NGO's.

Mister Muchenje is enthusiastic about the project and especially interest in how much money it is about. He sees potential for rural markets, but things it is difficult to unlock these markets. His company is on the moment mainly focussing on high income markets, but he says he is interested in expanding into rural.

Client Report

Company: Xmpla
Name: Mark Wells
Date: 15 may 2012
Meeting 1
Time of interview: 60 minutes
Tel: 0775892370
Email:mark.wells@xmpla.com

Highlights

Mark Wells works together with Phill Gibs from solar solutions Bulawayo. Phill Gibs is working mainly on small solar products. Mark Wells has a larger company that works on more than only solar. They have plans to merge Phill Gibs solar solutions with the company of Mark Wells.

Mark Wells had a research company in Europe and moved to Zimbabwe two years ago. He is now working all around sub-Sahara Africa, but he is living in Bulawayo.

On the moment he works together with 340 outlets that sell his solar products all over Zimbabwe.

Solar irrigation pump systems are one of the products he is selling. A system that could pump water up to 15 meters will cost around $1000.

He believes that market based business models are needed for sustainable businesses.

He thinks into the future and broad.

He loves to work with young people, on the moment he works together with a university (ABENESA). They supply him with employees with engineering background. He believes he will need more people in the future without academic education background.

He is interested to work together. He is looking for a next generation of new staff. He has experience with training people, and a network that is ready to use!

He does believe in a solar energy industry association of Zimbabwe. Because he thinks they will be incompetent, corrupt, slow and expensive. He sees no benefits from having such an association in Zimbabwe

His major problem on the moment is the stocking problem. These costs are high, and it is difficult to predict future orders. He uses tough stuff products and gets them from the UK. After he has ordered the products it takes 2,5 month before it is in store. He has to pay everything upfront.

He has a plan to work together with ZIMPOST to restock his stores (top secret)

Client Report

Company: Solar Solutions Africa
Name: F. Nyikadzino Gonese
Date: 5 June 2012
Meeting: 1
Time of interview: 70 minutes
Tel: 0775952046
Email: fgonese@solarsolutions-africa.com

Highlights

Solar Solutions started on the internet in 2007 with lighting Africa project. They have set up a collaboration with kudzi holdings to provide them a starting budget.

They worked together with the Chinese firs to import solar products. But after a an incident the Chinese left.

After that solar solutions started with a project on so it you self products. That where designed for people in the rural areas. He also came with a solar cell phone.

Gonese does understand why the GEF project failed, he agrees on the fact that this project was not sustainable. But GEF was good in way that people in rural areas learned about solar projects. After this projects education of rural population about solar products is a big problem.

On the moment solar solutions Africa is mainly working on the PV side of the solar market. But they also try to convince hotels to go into solar geysers and water heating. Payback time for is solar geyser is between 2 and 3 years.

They are also in biogas projects. Starting up pilot project for domestic use.

They played an important role in making solar product free of duty.

They think we need a association, to sustain solar energy markets for the future.

On the moment Solar solutions Africa is already building up a data base of young people who are interested in working in the solar business.

There is a strong need for more science and technology knowledge.

70% is not a problem, they think women might be more trust full.

Solar solutions Africa is ready to work with SNV. They really think that this could be a great cooperation.

Client Report

Company: Solar Electrical Engineering
Name: Chitembwe
Date: 29 May 2012
Meeting: 1
Time of interview: 25 minutes
Tel : 0772100607
Email:

Highlights

This meeting took place during solar seminar organised by Samansco.

Chitembwe is positive about working together with SNV. He thinks his company is suitable and he willing to put in time and money.

He is positive on the formation of a association. He thinks it is necessary to further develop the industry.

The GEF program was a great success according to Chitembwe.

The last year he did already a training program where he trained 35 young people in 4 villages.

He is worried about the finance part of the project. How are we going to finance this project?

Client Report

Client: **Madison Solar Company (Mutare)**

Date: **23/05/12**

Objective: **Meeting and presentation to the Heads of Departments**

Attendants: SNV- Gladys, Fungai, Chandi and Takawira (Solar Kings)

Highlights

- Solar Kings is a small company with its workers mainly from those who participated in the GEF Program.
- The company mainly manufactures (assembles) solar regulators and inverters and outsource panels and batteries for their installations
- The company prides itself in that it supplies its products to battery world which then distributes through its branches that are across the country.
- Solar Kings does refurbishment of solar systems that were installed for the workers in Dorowa and Mimosa
- Solar Kings also installs in rural areas for mainly domestic and general shops
- They were once involved in the training of 60 youths from the urban centres with a company named Solar Power but it was not successful because the youths could not go to the rural areas
- Solar Kings expressed concern to say, although the ILO program is something that is noble, there is need for financing especially to the consumers so that a market is created for the trained youth. They said they have some technicians who can be available for the training and they can invest time in the program
- From the discussions, it was seen that Solar Kings has no capacity and that they will need also need some capacity building on business management given the fact that a junior personnel was sent for the meeting which required a senior person who could make decisions
- 70 % women was achievable according to Takawira

Client Report

Client: **Madison Solar Company (Mutare)**

Date: **23/05/12**

Objective: **Meeting and presentation to the Heads of Departments**

Attendants: SNV- Gladys, Fungai, Andrea (Madison Solar Company)

Highlights

- Madison Company mainly installs large systems for schools, hospitals and orphanages
- Main distributor of Victron (American brand) products in Zimbabwe
- The company is of the view that the ILO program seems too ambitious given the fact that installation of solar systems is complex and will require well trained electricians
- Marketing can be sustainable but it will not fit with Madison line of business
- Madison offers products that are quite sophisticated with inverters and controllers that are programmed and thus a trained youth will not be able to meet the standards required
- Andrea indicated that he needed time to think about it and he will see how his company can play a role and see if there could be business for them
- Of interest to him is that, youths can be trained but there is need to secure market and that there must a financing scheme that would facilitate funds for end users to be able to purchase the solar systems so that there is business for them at the end of the day.
- Working with women will be good because he thinks that women work smarter than men
- He noted SEIAZ cannot be defined yet because there is no industry currently and competition will limit the goal of the association
- He was positive in all matters of the program but he showed that Madison will not have time and resources to invest in the program unless they can clearly define whats in it for them

Baseline Survey (1)

Baseline Survey Customers – lighting & entertainment

The kerosene user survey takes around 20 minutes to be administered by a trained enumerator per household.
It is also very import to review each survey by the end of the day to correct and clarify any mistakes and unclear information gathered.

The survey aims at collecting market information to enable companies to invest in rural markets for lighting.

0. Date

0.1	Date information collection	D	D	M	M	Y	Y	Y	Y
0.2	Enumerator								

A. General Information

A.1	Survey Number	
A.2	Names customer	
A.3	Sex respondent 1=Male 2=Female	
A.4	District	
A.5	Ward	
A.6	Village	
A.7	No. people living in household	

1. Household Demographics

1.1	Number of school age children in family?	
1.2	Number of children currently attending school in the family?	
1.3	Number of children currently using light for studying after dark?	

2. Current Lighting

2.1	Which of each type of lighting systems do you have?	*1=Yes 2 = No*	If yes, how many of each?			*1=Yes 2 = No*	If yes, how many of each?
a	Paraffin Lantern (small)			g	Candles		
b	Paraffin Lantern (medium)			h	Wood fires for light		
c	Paraffin Lantern (large)			i	Batteries		
d	Diesel Lantern			j	Solar lanterns		
e	Local paraffin lamp based system without glass cover			k	Other___________		
f	Torch light			l	None		

2.2	**Yesterday**, for how many minutes did you use a lighting system for each the following activity?					
2.2.1 Did you use light for any of these activities?		*1=Yes 2 = No*	2.2.2 How Many Minutes?	2.2.3 Who used it? *1=Yes 2 = No*		
				Mother	Father	Child
a	Cooking					
b	Eating					
c	Studying					
d	Preparing beds					
f	Attending to livestock/milking cow or goat					
g	Attending to baby					
h	Social Interaction (not including eating)					
i	Handicraft					
j	Outdoor Work (excluding attending to livestock /milking cow or goat					
k	Security/Night light					
l	Walking at night					

2.3	Last night, for how many minutes was the lighting system used total?	
2.4	Was last night a normal night for light use?	
2.5	If last night was not normal, then please indicate for how many minutes you typically use the lighting system.	

Baseline survey (2)

Baseline Survey Customers – lighting & entertainment

3. Paraffin

3.1	How often do you buy paraffin?	*1= daily* *2 = once a week* *3 = never* *4 = other*	
		If 4 = other indicate	….. times per week once every ….. weeks
3.2	How much do you spend on paraffin each time you buy it?		US$
3.3	a) How much paraffin do you buy each time?		litres
	b) if litre amount is not known, what container do they fill each time?	*1 = 1/4ltr bottle or container* *2 = 1/2ltr bottle or container* *3 = 1ltr bottle or container* *4 = 1.5ltr bottle or container* *5 = 2ltr bottle or container* *6 = 3ltr bottle or container* *7 = 5ltr bottle or container*	
3.4	How far do you travel to buy paraffin?		km
3.5	From whom do you buy paraffin?	*1 = local shop* *2 = fuel station* *3 = shop @ local business centre* *4 = local dealer*	
3.6	How far are you (kilometers) from the electric grid?		Km

3. Cell phone charging

3.7	Do you have a cell phone?	*1 = yes* *2 = no*	
3.8	If yes to 3.7 where do you charge it? …………………………………………		
3.9	How much do you pay for each charge?		US$
3.10	How often do you charge your cell phone?	*1= daily* *2 = once a week* *3 = never* *4 = other*	
		If 4 = other indicate	….. times per week once every ….. weeks

3.11	It is very important to me that I have a cell phone charging station close to my home.	*1= strongly agree* *2 = agree* *3 = disagree* *4 = strongly disagree*	
Give Reason:			

4. Importance of Light

4.1	Having light after dark is important for my household.	*1= strongly agree* *2 = agree* *3 = disagree* *4 = strongly disagree*	
4.2	Having light after dark is important for my children's education.	*1= strongly agree* *2 = agree* *3 = disagree* *4 = strongly disagree*	
4.3	We feel safe in our home after dark	*1= strongly agree* *2 = agree* *3 = disagree* *4 = strongly disagree*	
4.4	Our present system of lighting cause health problems.	*1= strongly agree* *2 = agree* *3 = disagree* *4 = strongly disagree*	

5. Entertainment

5.1	For how many hours a day do you listen to radio	*1= Not Applicable* *2 = up to 1 hour* *3 = 1 – 3 hours* *4 = 3 – 5 hours* *5 = over 5 hours*	
5.2	For how many hours a day do you watch TV	*1= Not Applicable* *2 = up to 1 hour* *3 = 1 – 3 hours* *4 = 3 – 5 hours* *5 = over 5 hours*	

	5.3.1 What source of power do you use for these devices?	*1 = yes* *2 = no*	5.3.2 How much does the power source you are using approximately cost in US$ per month?	
a	*Grid-electricity*		*Monthly bill*	*US$*
b	*Car battery*		*Total battery charge*	*US$*
c	*Batteries*		*All batteries*	*US$*
d	*Generator*		*Fuel*	*US$*
e	*Solar*		*Maintenance*	*US$*
f	*Other,……………………………………*			

Page 2 of 3

Baseline survey (3)

Baseline Survey Customers – lighting & entertainment

5.3.3a	If you charge a car battery, how often do you do so?	*1 = daily* *2 = once a week* *3 = never* *4 = other*		
		If 4 = other indicate	…….. times per week	
			once every ….. weeks	
5.3.3b	How far do you travel to charge a car battery?		km	
5.3.4a	How many batteries (AAA) do you buy per month?			
5.3.4b	How far do you travel to buy batteries (AAA)?		km	
5.4	How long have you had the Radio and/or TV?		Radio	Years
			TV	Years
5.5	At the time what was the price of the Radio and/or TV?		Radio	US$
			TV	US$

NOTES by enumerator:

WTP survey (1)

Enumerator:

Questionnaire No:

Name:

Date:

Location:

No:

Introduction

This part of the survey is used by a researcher from SNV Zimbabwe. We are carrying out a study about renewable energy with a focus on solar energy possibilities in the rural areas. With this research we try to develop a sustainable energy policy to provide people in the rural areas with light and energy. Your participation is completely voluntary and your responses will be **completely confidential.** Your participation in answering these questions is very much appreciated.

6. Education

6.1	What is the highest level of education you have completed?	0 = Did not go to school 1 = Primary school 2 = Secondary school 3 = Polytechnic/Apprenticeship 4 = Diploma colleges 5 = University degree 6 = Other, name grade ……………………………	6.1
6.2	Can you tell me the highest level of education of any one of the other adult household members?		6.2

7. Willingness to pay for solar products

Introduction

In this part of the survey I am going to ask you three questions about how much your family is willing to pay for different solar products. These products will provide you with light or/and a certain amount of electricity. When answering the willingness to pay questions keep in mind the amount of money you are spending on the moment on light and electricity. Please choose an amount of money which you can afford to spend.

The willingness to pay question is split up in two parts. Part one is a question about the price your family is willing to pay to purchase the product in once. Part two asks you how much money your family is willing to pay every month to rent/buy this product. This means how much your family is willing to pay every month to rent the system. After you have paid off the purchase price of the product, the product is yours and you don't have to pay rent anymore.

Willingness to pay solar lantern (product card 1)		
7.1	How much are you maximum willing to pay to **purchase** the solar lantern that is described at **product card 1**? (Fill in the chosen amount)	US$
7.2	How much are you maximum willing to pay **every month** to rent (rent to buy) the solar home system that is described at **product card 1**? (Fill in the chosen amount)	US$
Willingness to pay to solar home system (product card 2)		
7.3	How much are you maximum willing to pay to **purchase** the solar home system that is described at **product card 2**? (Fill in the chosen amount)	US$
7.4	How much are you maximum willing to pay **every month** to rent(**rent to buy**) the solar home system that is described at **product card 2**? (Fill in the chosen amount)	US$
Willingness to pay to solar home system (product card 3)		
7.5	How much are you maximum willing to pay to **purchase** the solar home system that is described at **product card 3**? (Fill in the chosen amount)	US$
7.6	How much are you maximum willing to pay **every month** to rent (**rent to buy**) the solar home system that is described at **product card 3**? (Fill in the chosen amount)	US$

WTP survey (2)

8. Household Income

Your answers will be treated completely confidential. You will not be contacted afterwards by anyone else about the answers					
8.1	Do you have any bank account	1 = yes 2 = no			
8.2	**Please estimate the total monthly income of your household (all income sources)?**		**US$**		
8.3	**What are the income sources of the household members and what is their monthly, annual or seasonal amount?**				
	(In case of season income, ask how many times a year the season takes place)	**US$ Per year**	**US$ Per month**	**US$ Per season**	**Number of seasons per year**
8.3.1	Cash income of all household members(salaries and other)				
8.3.2	Income out of sale of farm products Crop:____________				
	Income out of sale of farm products Second crop: ___________				
8.3.3	Income out of sale of livestock or poultry				
8.3.4	Income out of sale of Industrial products				
8.3.5	Income out of sale of other products				
8.3.6	Income out of repair and other services (maricho)				

			US$ Per year	**US$ Per month**	**US$ Per season**
8.3.7	Income out of pensions of retiree(s)				
8.3.8	Income out of remittances				
8.3.9	Other incomes (specify)	1			
		2			

9. Household Expenses

9.1	How much money did you spend last **month** on food and beverages (cooking oil and sucker etc.)?	US$
9.2	How much money did you spend last **month** on housing?	US$
9.3	How much money do you spend every **term** on education per child?	US$
9.3.1	Number of kids you pay money for education?	
9.4	How much money did you spend last **month** on cooking fuel?	US$
9.5	How much did you spend last **month** on lighting fuel?	US$
9.6	How much did you spend last **month** on transport?	US$
9.7	How much did you spend last **month** on airtime	US$
9.8	**What is the total amount of money you spend last month?**	**US$**

Thank you very much for your cooperation to this research

END

Payment cards (1)

Product card 1

How much is your family maximum willing to pay to **purchase** this product?

$ 0	$ 11	$ 33
$ 0.50	$ 13	$ 37
$ 1	$ 15	$ 41
$ 2	$ 17	$ 45
$ 3	$ 19	$ 49
$ 4	$ 21	$ 53
$ 5	$ 24	$ 57
$ 7	$ 27	>$ 57
$ 9	$ 30	Don't know

- Number of lights: 1
- Hours of light: 8
- Charge phone: Not possible
- Radio/TV: Not possible
- Lamp can be used for: working, studying, cooking, walking and socializing
- Portable
- 360degrees illumination

How much is your family maximum willing to pay **every month to rent/ buy** this product?

$ 0	$7	$ 22
$ 1	$8	$ 24
$ 1,50	$ 9	$ 26
$ 2	$ 10	$ 28
$ 2,50	$ 12	$ 30
$ 3	$ 14	$ 32
$ 4	$ 16	>$ 32
$ 5	$ 18	Don't know
$ 6	$ 20	

Payment cards (2)

Product card 2

How much is your family maximum willing to pay to **purchase** this product?

$ 0	$ 29	$ 90
$ 1	$ 34	$ 98
$ 4	$ 40	$ 105
$ 7	$ 45	$ 120
$ 10	$ 52	$ 135
$ 13	$ 60	$ 150
$ 17	$ 68	$ 170
$ 21	$ 75	>$ 170
$ 25	$ 82	Don't know

How much is your family maximum willing to pay **every month to rent/ buy** this product?

$ 0	$ 9	$ 33
$ 1	$ 12	$ 36
$ 1,50	$ 14	$ 40
$ 2	$ 16	$ 44
$ 2,50	$ 18	$ 48
$ 3	$ 21	$52
$ 4	$ 24	$ 56
$ 5	$ 27	>$ 56
$ 7	$ 30	Don't know

- Number of lights: 1
- Hours of light: 12
- Charge phone: One phone/day
- Radio/TV: Not possible
- Lamp can be used for: working, studying, cooking, walking and socializing
- Portable
- Illuminates entire room

Payment cards (3)

Product card 3

How much is your family maximum willing to pay to **purchase** this product?

$ 0	$ 40	$200
$ 1	$ 48	$ 250
$ 2	$ 65	$ 300
$ 5	$ 75	$400
$ 9	$ 90	$ 500
$ 13	$110	$ 650
$ 18	$ 130	$800
$ 24	$ 150	>$ 800
$ 32	$ 170	Don't know

How much is your family maximum willing to pay **every month to rent/ buy this product?**

$ 0	$ 16	$ 48
$ 1	$ 18	$ 52
$ 2	$ 21	$ 56
$ 4	$ 24	$ 60
$ 6	$ 27	$ 64
$ 8	$ 30	$ 70
$ 10	$ 33	$ 76
$ 12	$ 36	>$ 76
$ 14	$ 44	Don't know

- 40 Watt solar home system
- Multiple lights
- Hours of light: continues
- Charge phone: Multiple/day
- Radio connection: yes
- TV: up to 2 hours/ day
- Small fan: Yes
- System can be used for : working, studying, cooking.
- Electricity system
- Illuminates entire house
- Possible to expand the system with more panels