universität OLDENBURG

DESIGN OF A BATTERY CHARGING STATION IN MOZAMBIQUE

by

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RENEWABLE ENERGY

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PPRE

Anyone who has never made a mistake has never tried anything new.
Albert Einstein

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Abbreviations

AMES-M	Access to Modern Energy Services-Mozambique
BCC	Battery charge controller, also Battery charging unit BCU
BCS	Battery charing station
DEEP	Developing Energy Enterprises Project
DOD	Deep of discharge
EdM	Electricidade de Mozambique (Electricity of Mozambique)
EnDev	Energising Development
FUNAE	Fundo de Energia (Energy fund)
GDP	Gross Domestic Product
GIZ	Gesellschaft International Zusammenarbeit (German International cooperation agency)
Hh	Household
INE	Instituto Nacional de Estadistica (National Statistics Institute)
SBCS	Solar battery charging station
SBS	Solar business system
SHS	Solar home system
SOC	State of Charge
SOH	State of health
STC	Standard test conditions
MFI	Micro finance institution
MHPP	Micro hydro power plant
MSME’s	Micro small and medium-sized enterprises
Mt	Metical (Mozambique currency)
NPV	Net present value
PUE	Productive use of electricity
U	Voltage (V)
W	Watt
Wh	Watt-hour
Wp	Watt-peak

Executive Summary

Mozambique is one of the least developed countries in the world[1], access to electricity being a mayor concern. For this reason, the Dutch German partnership, Energising development EnDev, is actively working in Mozambique throughout the AMES-M project.

One of the key interventions for AMES-M is to provide modern energy for lighting and small electric appliances to households through **Battery Charging Systems.**

The objective of this study is to perform a technical and economical analysis of the feasibility of battery charging stations in Mozambique. It answer the questions: “Are BCS technically and economically feasible in Mozambique?” if so, “Which setup (technology and PUE combination) is recommended?”

The study was done from October 2011 to February 2012, with 2 months of work field in the Manica province. All the prices used are the prices in Mozambique at that time.

At first a general overview of the country situation of Mozambique, Manica province and best practices of battery charging stations in Africa are presented in the first part of this study.

Then a technical and economic feasibility evaluation of 3 systems is performed:
•Solar business systems SBS, A household size SHS (120 Wp) plus productive use of electricity PUE, like charging cellphones, charging lanterns, barber shop , cinema[2], etc
• Solar battery charging stations SBCS, SHS for starter battery charging, 600 Wp for Lead acid 70 Ah battery charging.
•Micro hydro power MHP for starter battery charging, Using electricity from the MHPP mini grid to charge 70 Ah lead acid batteries.

For the technical feasibility a comprehensive analysis of the energy losses in the components is performed. The result is a recommendation of the optimal size of the components of each system to balance the capacity and the potential share of productive use of electricity.

[1] HDI 2011, ranked in the 184 of 187 countries UNDP (2011). Human development index trends 1980-2011.

[2] Use a TV set to play a movie For more information refer to the section 4.1.2

For the economical feasibility net present value and cash flow analysis are performed for the 3 options assuming the operator pays 100% for the system.

The main findings of the research are:

- Starter battery charging stations are neither technically nor economically feasible for Mozambique. The main limitation is the high cost and short lifetime of the starter batteries. When it is possible to supply the same service with other modern forms of energy, this should be preferred over the starter battery.

- Solar business systems ,SBS, are technical and economically feasible. By including productive use of energy the economic and social development can be boosted. The operator has an extra source of income and can pay for the system.

- Nevertheless, one obstacle that needs to be overcome is the high up front cost of the SBS, for this reason it is recommended to look for cheaper financial options than the commercial bank, for example Funae.

Finally a proposal for the implementation of this SBS in Mozambique is presented, a SWOT analysis and a qualitative risk assessment.

1. Introduction

This chapter provides a description of Mozambique, Manica province and Chimoio city (where the BCS are going to be implemented), as well as a description of GIZ Ames-M project. It was written in cooperation with Juan Pablo Villa, another PPRE student who worked in Chimoio at the same time and for the same organization.

1.1 Mozambique country situation

QUICK FACTS		Explanation
Population (million)	23,4	Year 2010
GDP per capita (US$)	410	Year 2010
HDI	0,317	Place 184 of 187 Countries.
Rural population (million)	14,4	
Life Expectancy (years)	49	
Literacy rate (%)	55	% of people ages 15 and above.
HIV (%)	14	Total (% of population ages 15-49)
Poverty index (%)	54,7	Under the national poverty line.(2008)
Electrification rate (%)	16	Connected to the national grid (EdM)

Table 1: Synthesis of the main socio-economic indicators of Mozambique
Source: Data world bank and UNDP (Group 2011)(UNDP 2011)

1.1.1 Location

Mozambique is located in the southeastern Africa bordered by the Indian Ocean to the east, Tanzania to the north, Malawi and Zambia to the northwest, Zimbabwe to the west and Swaziland and South Africa to the southwest.

The total area of Mozambique is 799380 km2, from North to South to the East it has coastline with the Indian Ocean for over 2515 km (Estadistica 2011).

Figure 1. Mozambique geographical location

1.1.2 Political division

Mozambique is divided into ten provinces and one capital city with provincial status.

1. Cabo Delgado
2. Gaza
3. Inhambane
4. Manica
5. Maputo (city)
6. Nampula
7. Niassa
8. Sofala
9. Tete
10. Zambezia

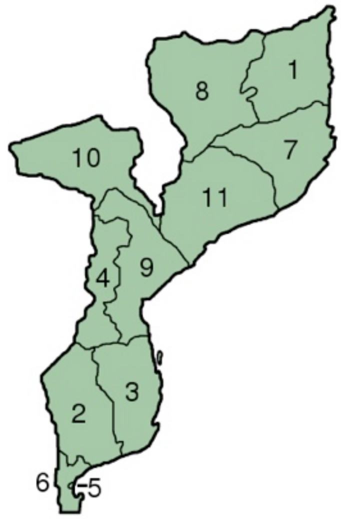


Figure 2: Provinces of Mozambique

1.1.3 History

Portugal began to colonize the area that later became Mozambique in the early 16th century. In 1974, with the Frelimo independence movement, Portugal colonial rule ended after ten years of war.

The Renamo movement, an anti-Frelimo resistance group supported by Rhodesia and South Africa, fought Frelimo in the 1977-1992 civil war. This conflict, combined with the central economic planning by the Marxist leadership of Frelimo, left the country in chaos. About a million people died in the civil war.

Frelimo inaugurated a new constitution in 1990 that enshrined free elections, and both sides signed the resulting Rome Peace Accords of 1992. Frelimo has won all subsequent elections, some of which have been disputed by Renamo and smaller opposition groups. Political life has nonetheless remained stable.(BBC)

1.1.4 Culture

Mozambique has been the home of various different groups Bantu, Swahili, Arabs, Indians and Europeans.

Traditional ways of life are well preserved in Mozambique culture - varying from province to province. This cultural kaleidoscope provides visitors with a host of treasured experiences and memories. The Makonde, from Cabo Delgado Province in the north-east, are known for their fearlessness and initiation rituals. For male initiation, participants dance in 'mapico' masks.

Music is part of the culture of Mozambique and is very important to the Niassa people who live in the sparsely populated North-western region.

The traditional, spicy cooking of Zambézia, Mozambique is highly regarded. Zambézian chicken, grilled with palm oil, is a particular delicacy. The agility of the Nhau dancers of Tete Province is much admired. To the sound of resounding drum beats, they dance holding huge and frightening wooden masks. For the Chope people of Inhambane Province the 'timbila' is both the name of a percussion instrument and a dance.

Regarding religion the mayor groups in Mozambique are:
Christians 56%
Muslims 18%
Other beliefs 7%
No religious beliefs 18%

Portuguese is the official language but Makua-Lomwe, Swahili, other indigenous languages are also spoken in different regions.

1.1.5 Geography

The country is divided into two topographical regions by the Zambezi River, the largest and most important in the country.
To the North of the Zambezi River, the narrow coastline moves inland to hills and low plateaus, and further West to rugged highlands.
To the South of the Zambezi River, the lowlands are broader with the Mashonaland plateau and Lebombo mountains located in the deep South.

1.1.6 Climate

Mozambique has an inter-tropical climate with two seasons, a wet season from October to March and a dry season from April to September. Climatic conditions, however, vary depending on altitude.

Rainfall is heavy along the coast and decreases in the north and south. Annual precipitation varies from 500 to 900 mm depending on the region; with an average of 590 mm. Cyclones are common during the wet season (Wikkipedia 2011).

1.1.7 Energy situation and resources

Biomass is by far the country´s predominant energy source, few people have access to modern forms of energy such as electricity (only 16%, most of them concentrated in the urban areas). Nevertheless, Mozambique is self sufficient in energy resources with the exception of liquid fuels; Table 2 summarizes the renewable and fossil fuels energy resources.

Power generation is dominated by the hydroelectric facility Cahora Bassa, located on the Zambezi River in western Mozambique. It contributes significantly to the installed capacity in Mozambique and exports 2/3 of its output to South Africa and Zimbabwe. Due to the low population density, 29 inhabitants/km^2 and Germany 235 inhabitants/km^2, combined with to the low consumption per household make it financially complicated to distribute grid connected commercial sources of energy.

Electricidade de Moçambique EdM, responsible for transmission, distribution and commercialization. EdM is not strictly a government organization, but a government owned corporation. (Gunther 2010)

Resource	Availability	Comments
Wind	Wind resource along coast, Niassa Average wind speed 6 m/s	4 sites studied, resource mapping needed
Solar	4.5-7 kWh/m2/day Surface annual irradiation 1.49 PWh/year	Assuming 5.2 kWh/m2/day Mozambique land surface receive 1.49 PWh/year
Hydro	13 GW. Where 1000 MW expected to be Small scale (Up to 10 MW)	> 60 potential projects
Biomass	In order of hundreds of MW. Bagasse potential availably 433 thousand tones.	5 sugar plantations in Maputo and Sofala.
Gas reserves	Estimated 700 billion cubic meters	Potentially generate 500 MW for over 300 years
Coal reserves	Estimated 3600 Mt, equivalent to 140 million TJ	Potentially generate 5000 MW for over 100 years

Table 2. Renewable energy resources potential
Source: (Hankins 2009; Hellpap 2011)

1.2 Manica province

EnDev decided to work only in the Manica province, therefore more specific information about it is presented in this section.

QUICK FACTS		Explanation
Population	1,438,386 hab.	
Rural Population	74,7%	
Life expectancy	49.1 years	
Literacy rate	41,5%	% of population ages 15-49.
HIV rate	19,7%	% of people ages 15 and above.
Poverty Index	43,6%	Under the national poverty line
Electrification rate	11,5%	Connected to the national grid

Table 3: Synthesis of the main socio-economic indicators of Manica
Source: Data world bank and UNDP (Group 2011)(UNDP 2011)

1.2.1 Location

The Manica Province is located in the west area of Central Mozambique.
Bordering in the North with Province of Tete, South with Inhambane and Gaza Provinces, East with Sofala Provinces and West with Zimbabwe has a total area of 61,661 km^2, and a population of 1.43 million habitants (INEM 2007).

Manica Province is located in one of the highest areas of the country and gives birth to several rivers that flow east towards the Indian Ocean. (Zana 2011),(Wikkipedia 2011). Also, Manica is the gateway with western neighbor Zimbabwe which makes it an important economical center.

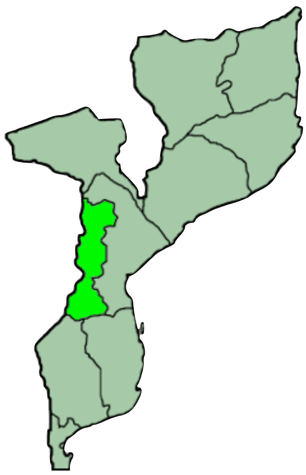


Figure 3. Manica province location

1.2.2 Political Division

Administratively is divided in 10 districts: Báruè, Gondola, Guro, Machaze, Macossa, Manica, Mossurize, Sussundenga and Tambara.

1.2.3 Chimoio city

Chimoio is the capital of Manica Province and represents the economical center of Manica. With a total population of 238,976 inhabitants, it occupies the 5th place in the more populated cities in the country (INEM 2007).

Chimoio's name under Portuguese administration was known as Vila Pery. Vila Pery was developed under Portuguese rule as an important agricultural and textiles centre. The change in name from Vila Pery to Chimoio took place on 12 June 1975, during the public rally of the first President of independent Mozambique - Samora Moisés Machel.

The town lies on the railway line from Beira to Harare (Zimbabwe), near the Cabeça do Velho rock, located about 95 km from the Zimbabwean border.

Figure 4. Mountain Cabeça de Velho, Chimoio

After the Zimbabwean political and social crisis of the 2000s, Chimoio has become a major destination for immigrants who were looking for work in Mozambique, and today is sometimes described as feeling more Zimbabwean than Mozambican.

1.2.4 Geography & Climate

The province of Manica stretches along the border with Zimbabwe to the West of Mozambique. It is generally characterized by the Vumba, Chimanimani and Nyanga mountain ranges which form the border with Zimbabwe. With a peak altitude of 2,436 metres, Mount Binga is the highest mountain in the country.
Temperature wise, the average highest per year are above 30ºC (with peaks of above 40ºC) and the lowest is around 11ºC with an average of 22ºC throughout the year. (Climatedata.eu 2011) During the rainy season the amount of rain is very high, making even the transportation or communication with rural and semi-rural areas impossible

1.2.5 Energy resources

Wind

The average wind speed in the landlocked areas of Mozambique is in general less than 2 [m/s]. Probably there are sites around the mountainous areas with more favorable conditions. In a general perspective, the conditions in the province are not good for electricity generation using wind. There are certain specific applications where wind energy could be used, and has been used to an small extent, for example, water pumping. (Klaus 2005)

Solar

Manica has a high solar irradiation level, with a yearly average of 5.4 kWh/m^2/day with a monthly variation between 4.2 and 6.3 kWh/m^2/day. (Klaus 2005)

Biomass

The current resource exploitation of fire wood has in most cases a devastating effect. Meanwhile, a sustainable usage of Miombo (indigenous tree) of forests and areas of agro-forestry presents high renewable potential for charcoal generation.
On the other hand, compared with other provinces, Manica has a high index of agro production. Due to this, there is also a high quantity of residuals, both humid and dry, and therefore a good energy potential. The wood production industry in the province does not explore the energy content on the rest and residuals from their production. Also the biomass potential could be increased by cultivating certain species of grass, woody plants and vegetal oil. (Klaus 2005)
Today large areas are being planted with Jatropha to produce biodiesel following the national objectives for this source of energy.

Hydropower

The mountainous areas on the West side of the province show a high rain level throughout the year. There are several small and medium sized rivers with permanent water level that would be appropriate for micro and pico hydropower systems. (Klaus 2005)

Studies from different sources have shown the high potential that the province has to generate this type of renewable energy, this was known since colonial times, and is still possible to find old setups in rural areas.

1.3 GIZ-AMES-M Program

1.3.1 GIZ

GIZ operates in more than 130 countries worldwide. In Germany, GIZ maintains a presence in nearly all the federal states. Our registered offices are in Bonn and Eschborn. GIZ has more than 17,000 staff members across the globe – some 70 % of whom are employed locally as national personnel. In addition, GIZ places or finances around 1,110 development workers, 700 integrated experts, 455 returning experts and 820 volunteers worldwide.

Figure 5: GIZ logo

The services delivered by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) GmbH draw on a wealth of regional and technical expertise and tried and tested management know-how. As a federal enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development. GIZ is also engaged in international education work around the globe (GIZ 2010).

1.3.2 EnDev

The aim of the Dutch-German partnership, Energising Development (EnDev), is to provide **five million people in developing countries with sustainable access to modern energy services by 2015**.

During the first phase of Energising Development (2005–2009), the target was to reach 3.1 million people. The activities of EnDev focus on providing access to modern and clean energy services to poor households, small enterprises and social institutions in rural areas.

The energy services include:
1. Energy for lighting and household appliances
2. Energy for cooking
3. Energy for social infrastructure
4. Energy for production and income generation

1.3.3 AMES-M

The project “Access to Modern Energy Services-Mozambique - AMES-M”, started its activities in Mozambique at the beginning of the year 2007.
The duration of the first stage of the AMES-M project was 3 years, from early 2007 until ends of 2009. Among the many activities the project was involved, we can mention:
-Improvement of the electrical grid in the cities of Maputo and Matola.
-Financing 4 small hydropower stations in the province of Manica.
-The promotion of small solar home systems in the province of Sofala.
(Madeira 2011)

The second stage of the project extends until 2012 and is mainly focused in the province of Manica. It has for key objectives:
-Provide modern energy for lighting and small electric appliances to households through Micro/Pico-Hydro, Grid Densification and **Battery Charging systems.**
-Provide modern energy for productive use by small and medium-sized enterprises, craftsmen for employment creation and income generation.
-Capacity building of local NGOs, Private Sector, Banks and Partner Institutions. (Ministry of Energy, FUNAE)

-

AMES-M coordinate its activities in close cooperation with FUNAE and government structures both central and in the province.

Figure 6: Ames-M team

2. Battery charging stations

This chapter describes the AMES-M motivation for promoting BCS, also defines what a battery charging station is, and finally compares best practices in the field.

2.1 Scope and limitations of this study

As mentioned, one of the key objectives for the second stage of EnDev Mozambique Ames-M is to provide modern energy for lighting and small electric appliances to households through **Battery Charging systems.**

In the rural areas of Manica province there are some PV installations in hospitals and schools that are suspected to be misused by charging cellphones. This causes the battery operate constantly in a low state of charge, reducing their lifetime. The most critical part is that sometimes the community does not have the money or knowledge to replace the battery, so when the battery fails, the complete installation stops working as well.

The service life of the complete installation is considerably reduced due to the lack of technical knowledge of correct operation and system maintenance.

Another reported situation is the growth of informal cell phone charging market. The figure 7 shows examples of such charging stations. These stations operate by connecting a second hand PV module to a second hand car battery directly, without any charge controller.

Figure 7. Informal mobile charging station in Manica

These installations represent a health risk for the operators and the community, due to the bad quality of the electric connections and the old lead acid batteries that may have some leakages.

To tackle these two problems, *abuse of current installations and health risk of informal charging stations*, EnDev Mozambique decided to work in the development of a concept of a new BCS . “EnDev goal is to identify suitable BCS owners and managers, and support the elaboration of a workable business plan". (Hellpap 2011)

The objective of this study is:
Perform a technical and economical analysis of the feasibility of battery charging stations in Mozambique. It aims to answer the questions: Are BCS technically and economically feasible in Mozambique? if so, Which setup (technology and productive use of electricity PUE) is recommended?

This study concentrates only in Manica province, where Ames-M is concentrating its efforts. For the solar home system only the sales model is considered because there is no evidence of a fee based service business model is operating in Mozambique.

EnDev is an output based project; the aim is to provide as many households as possible with modern energy services. In order to account the total beneficiaries in the different EnDev projects in a comparable way, standardized rules for calculating "EnDev beneficiaries" have been developed and are presented in detail in the section 2.1.1.

2.1.1 EnDev Counting

EnDev is a result based project, therefore monitoring is a essential component. There is a standard methodology to count the number beneficiaries of each project.

Different service level provided accounts for different share beneficiaries reached; giving access to modern energy to someone by connecting the user to the grid is not the same as giving him a Pico PV system, therefore the counting needs to be differentiated.

The basic rules for counting beneficiaries are summarized in the next table:

Service Level	Service Package	kWh per person per year	kWh per person per day	Typical delivery system	People count as ..
Full	All you want	1000	2,74	Grid	1
Advanced	Basic + fan, video, fridge	100	0,27	Minigrid	1
Basic	Light CFL/LED, Radio, TV, Mobile Phone	10	0,027	SHS	1
Partial	Less light, Radio, Mobile Phone	3	0,008	Battery Charging	2/3
Minimum	Even less light	1	0,0027	Pico PV lantern	1/3

Table 4 : EnDev rules for measuring outcomes
Source: EnDev wiki (Raabe Tim 2011)

For the propose of this study, the basic, partial and minimum service levels are relevant.

The categories are classified by kWh **per person per year.** This can be easily converted to kWh per household as follows:
Assuming 1 household= 5 persons
1 household = 50 kWh/year= 135 Wh/day

The number of EnDev beneficiaries is an important parameter while deciding between the different options for the BCS.

2.1.2 Energy access and productive use of electricity

Access to reliable and affordable energy services can generate local jobs, income and, thereby, promote local development (Brüderle 2011)..

However due to the high price of the systems in some cases the households cannot afford them. In contrast it has been reported by other SHS programs that only 10-15% of the households are using their system for income generation. (Blunck 2008). Including a productive use of electricity. Households could have the possibility to have an extra source of income that would help them to pay for the system.

Another significant point is that countless electrification programs have suffered from a "lower" demand response of the commercial sector than expected. Consequently, the programs do not have the impact forecasted and the electrification schemes suffered from a lack of new customers being able to pay for their electricity (Brüderle 2011)..

For this reason, GIZ and Energy Sector Management Assistance Program (ESMAP) from World Bank started a joint project in 2006 in which the impacts of electrification on small and micro enterprises in Sub-Saharan Africa were systematically analyzed. From this work:
"*Concrete and dedicated activities should wherever possible complement energy access programs so that they result in the productive use of the newly available energy services and, thus, promote income generating activity and local job creation*" (Brüderle 2011).

Afterwards GIZ and the EUEI PDF decided to jointly start the 'PRODUSE' initiative and publish "The Productive Use of Electricity Manual". In this manual productive use of electricity is defined as:

"*An agricultural, commercial and industrial activities involving electricity services as a direct input to the production of goods or provision of services"* (Brüderle 2011)..

For the design of the battery charging station, different possibilities of PUE of low power and day light activities are explored. Productive use of electricity is strategic feature to be considered during this study, PUE's objective is to increase income growth as well as local employment generation.

2.2 Battery charging station

A battery charging station is a central facility where charging service of some or all of the next components is provided:

- -Starter Batteries 12 V
- -Cellphones (Section 2.3)
- -Lanterns

In addition others examples of PUE within the BCS can be offered such as: Cinema, barber shop, handcraft workshop, etc.

This BCS can be powered either from the grid or from renewable energy sources such as solar or hydro power.

The size of the installation, number of devices charged per day, cost and business-operational models are variable. Examples of best practice are can be found in the section 2.4.

2.3 Off-grid Cell phone charging
US$2.3 Billion Market Opportunity

There are more than 4 billion mobile connections worldwide (GSMA 2009). Over the coming years, many more millions of people in rural areas are expected to acquire mobile phones because of the benefits associated with access to communication. Most of these new subscribers will not have direct access to electricity.

Figure 8: Phone access
Source: GSMA

It is also suggested that the need to recharge phones is a significant driver of demand for rural electrification. People have traditional alternatives for lighting and cooking but for phones they need exclusively electricity.(GSMA 2009)

The lack of a constant source for recharging a phone is a big constraint; it can result in missed calls, which implies a decrease in airtime revenue for mobile operators. For this reason rural electrification is extremely relevant for mobile operators.

If there are 1.6 billion people in the world without access to grid electricity, GSMA and Wireless Intelligence research, estimates that 30% of those people have a mobile phone connection. This means nearly 500 million people currently have access to a mobile phone but do not have their own means for charging it. Field studies show that when a constant source of charging is available the usage increases by 10%. Considering average airtime spending of the average off-grid customer (US$4 per month), the expected increase in direct revenues would total US$2.3 billion per year. (GSMA 2009)

Specifically in Africa this situation is critical, a study carried out between February and April 2011 by Developing Energy Enterprises Project (DEEP) in Uganda, Kenya and Tanzania shows:

- Phone charging is a highly viable economic activity.
- Phone users report significant economic and social benefits from the use of their phones.
- There is considerable unmet need and significant potential for phone charging micro businesses to grow.
- The major constraint on growth is lack of access to funds for the purchase of panels and accessories.
- These businesses represent a viable, cost efficient and sustainable way of addressing the phone charging needs of off grid subscribers.

For instance, Mozambique has an increasing number of cellphones as showed Table 5.

Year	Cellphone per 100 people
2006	11
2007	14
2008	20
2009	26

Table 5: Mozambique cellular subscriptions

Source: Data world bank (Group 2011)

Clearly there is a trend to increase the number of cellphones, for example from 2006 to 2008 the percentage was doubled (Group 2011). As a result the demand for electricity to charge cellphones is also increasing.

2.4 Examples of Battery Charging Stations

A comparison of some relevant examples of Battery Charging Stations is presented in Table: 5 Example of BCS. It is especially important to give attention to the experience of EnDev in other African countries.

Table 6: Example of BCS

	Country	Energy source	System size	Type of battery	Charging capacity [1]	Investment capital	Ownership	Fee	Comments
EnDev	Burundi	Solar	-------	Starter [2]	2 batteries per day	50% the operator 50% EnDev	Private	Fee per service [3]	Offer the project to shop owners with the capacity to pay for 50% of the investment.
	Mali	Solar	390 Wp	Starter [2] 70 Ah	3 batteries per day	10-20% community 80% EnDev	Communal	Fee per service 600 FCFA [4] (US$ 1.2)	26 SBCS built by 2009
			780 Wp		6 batteries per day				
DEEP	Tanzania	-Solar -Grid	58 Wp 180 Wp	Starter [2] +BCC [5]	20 phones per day	100% operator	Private	Fee per service (US $0.17)	78 BCS are enrolled in the DEEP programme in Tanzania
	Uganda	-Solar -Grid	50 Wp 80Wp	Starter [2] +BCC [5]	8 phones per day	100% operator,	Private	Fee per service (US $0.25)	26 BCS are enrolled in the DEEP programme in Uganda
Osram UNIDO	Kenya	Solar	9.2 kWp	Starter [2] +BCC [5]	-O box -O Lamp -Mobiles -Water purification	UNIDO +Donors OSRAM	Communal	Fee per service leasing system	3 Hubs in operation in Suba district.
E.quinox	Rwanda	Solar	570 Wp	Starter [2] +BCC [5]	-Battery boxes (Batt+ BCC)	100% E.quinox	Communal	Fee per service recently try monthly fee	3 systems in Rwanda and 1 in Tanzania. First system 2009

Notes:
[1] Estimation of the average number of batteries. It is difficult to estimate the capacity in Ah due to the significant differences in the SOH and SOC of each battery.
[2] Starter= Car Lead acid battery
[3] Fee charged every time the battery or mobile phone is charged.
[4]1 US$= 500 FCFA
[5] BCC= Battery charge controller

2.3.1 EnDev

EnDev has Battery Charging Stations in Mali, Burundi, and in soon in Ethiopia as well. According to EnDev experts, SBCS can be an economic solution in areas (Michael 2011) :

- Remote not connected to the grid.
- Diesel fuel costs and battery transport costs are high.
- Low income.
- Low energy demand.

Important aspects to be considered for the success of SBCS are (Michael 2011):

- Extensive marketing.
- Additional services to be offered such as selling solar components, or cutting hair.
- Training of all local operators and technicians.

2.3.2 Burundi

A few facts about Burundi (Heidtmann 2011):

- Only 2 % of the population has access to electricity.
- Households have a very limited budget.
- Grid connected battery charging stations already exist in the main cities.
- People from rural areas require long journeys (40 km and more) for a battery charge.
- Quality of charge is often deplorable.
- Batteries are being charged directly from the PV panel without a charge controller.

BCS's in Burundi consist of 85Wp-170 Wp for charging cellphones and 2 small batteries per day. Additionally in these centers Pico PV Solar Lanterns (SL), SHS and PV-Pumps will be promoted and sold.The promotion is done through sales exhibitions "road shows" near the most frequented markets and churches. At least one exhibition every week, followed by a second visit some weeks later, allowing potential customers to collect the money meanwhile.

BCSs are integrated in existing shops, therefore shop keepers do not only depend on the income generated by charging batteries since they diversify their income sources. The SBCS's are owned by a private operator providing services on a fee based service.

For the operator selection, the following has has been established:

- Shops built of concrete will be prioritized instead of wooden shops to secure the equipment inside.

- First come, first serve. The first operator who is able to pay the contribution of 50 % will be the beneficiary. (EnDev will pay the other 50%)
- Private operator will be sensitized about the proper use of the systems and the necessity of maintenance. (Heidtmann 2011)

2.3.3 Mali

Figure 9: BCS in Mali

A few facts about Mali from Energypedia (Natascha 2011).:

- Access to Electricity 17%, but in urban areas is as high as 51%.
- Electricity accounts for only 3 % of Mali's energy consumption.
- Extreme poverty denies access to modern energy services to much of the population.

Two different kinds of stations were constructed: a small system with the capacity to recharge 3 batteries per day (390 Wp) and a big one with the capacity of 6 batteries per day (780Wp). The system consists only on PV modules connected to the battery charger (Steca PL 2085).

Until 2009, 26 SBCS were constructed. The communities contributed with 10 to 20 % of the initial investment costs (in cash and in kind). The remaining 80 to 90 % was covered by EnDev funding. The SBCS are owned by the community and their operation is delegated to a private service provider, who runs them on a fee based service. The income generated from the SBCS is supposed to cover the maintenance and upgrade costs of all the installations (including key public buildings).

Key interventions in setting-up institutional framework by agreement on the management committee selection of the community, assignment of duties/ rights for operator and finally stakeholder supervision were established.

Options for autonomous up-scaling beyond the project boundary are limited; initial investment costs are high and largely subsidized; as setting up the fund for maintenance and repair already proves to be difficult, excess funds for up-scaling in this set up are unlikely (Natascha 2011).

2.3.4 Uganda and Tanzania

98% per cent of rural households in Tanzania lack access to electricity. The equivalent figure for Uganda is 96% (Collings 2011).

The program Developing Energy Enterprises Project DEEP supports micro-businesses engaged in servicing the Energy needs of poor communities in Kenya, Tanzania and Uganda.The aim of the program is to strengthen the business practices of the participating entrepreneurs, support them in accessing small loans, and facilitate market linkages through information sharing and network building.

By June 2011 a total of 132 phone charging businesses were actively participating in the program - 78 of them in Tanzania, 28 in Kenya and 26 in Uganda.

Average system size is 50-80 Wp. Installations are generally performed by trained technicians but in a few cases by the owner himself. In almost all cases, the systems were paid for out of the owners' savings or with support from other family members. Only one entrepreneur had taken a loan from a bank. In two cases the entrepreneur were using a battery which was recharged every few days from a charging station using grid electricity. Both of these entrepreneurs had purchased solar panels but these had been stolen before they could be installed. In one case, the business owner was using grid supply, with an inverter and battery providing back up when the grid was down.

From February to April 2011, a research was undertaken to better understand the marketing practices and challenges faced by a range of energy micro-businesses involved in the DEEP program. (Clough 2011)

The key findings from this study are as follows (Collings 2011):

- Average price is 20 US cents per charge, which appears standard across the region (informal agreement amongst phone charging businesses)
- *Customers charge their phone on average 3 times a week.*
- The phone charging services reported lots of competition- two of the six said they had more than 7 competitors.
- Entrepreneurs operating from their home also used the solar PV system for lighting and TV.
- There appears to be scope to expand into other phone accessories and possibly solar lanterns.
- Operators who ran grocery stores said the phone charging was more profitable than the store.

2.3.5 Kenya

A few facts about Kenya (Loy 2011):

- 75% of the population does not have access to electricity.
- The average Kerosene consumption/month = 10 liters / household equivalent to US$ 10 or more.
- Heavy dependency on wood fuel and other biomass that account for 68% of the total energy consumption (petroleum 22%, electricity 9%, others 1%)

There are 2 different types of battery charging stations in Kenya, the UNIDO energy kiosks and the OSRAM energy hub.

UNIDO energy kiosk

A typical Kiosk of 10-30 kWp of solar power serves 1000 - 3000 households (5000-15000 inhabitants). Kerosene lamps are replaced by high efficient rechargeable LED lamps *which need to be recharged once a week.*
500-1000 mobiles for 2000 homes are recharged on a 3 days basis and 50 car batteries are going to be recharged twice a month.

The cost for setting up a kiosk is around US$25,000 - US$150,000, this amount will be provided by UNIDO + donors. The energy kiosk remains property of the community.(Varaghese 2010)

The OSRAM energy hub

Alternative energy services for lighting, mobile phone charging and drinking water treatment for the rural fishing communities in Suba District – Kenya. Main emphasis of the project is to replace kerosene based lighting in households and fishing sector with efficient CFLs powered by batteries charged with solar energy, provided by Solar panels. (e.g. 42 Solarworld SW 220 panels with a performance of 220 Wp each).

Figure10 :Energy hub (left) O-Box with O-Lamp (right)
Source: OSRAM Kenya

O–Hub is equipped with:
• A battery charging station for the O-box and battery powered lantern
• A NOKIA mobile phone charging station
• A water purification and sterilization plant with rainwater harvesting and collection System
• A sales room, storage, and office.

O-Hubs are further leasing, sale and service points for OSRAM products based on renewable energy technologies, as well as a recycling and *collection point for end-of-life products*.

The reproduction of a standard installation allows taking advantage of economy of scale effects. So far 3 O-Hubs are operating in Suba District: Mbita Town, Sindo Town and Nyandiwa. (Mair 2010)

2.3.6 Rwanda

E.quinox is a non-profit, humanitarian project that aims to bring cost-effective, sustainable renewable energy to developing countries. Founded by students from different departments at the Imperial College in London equinox installed their first system in 2009.

Figure 11. Energy kiosk in Minazi, Rwanda 2010
Source: E.quinox

The Energy Kiosk concept designed by E.quinox is centralized station for electricity generation to be consumed in a decentralized way via battery boxes[3]. The battery boxes are given to the customers against a small deposit as well as a payment for the recharge.

With the battery box lights and other small electronic devices, such as mobile phones, radios and shavers can be powered, because the electricity provided is already AC.

Regarding financing, E.quinox make 100% of the initial investment, and the community pay based on the monthly revenue. ideally the cost of the kiosk is recovered over a period of seven to ten years, and then, the systems will be handed over to the local governments or communities.

[3] Battery box is the integration of a battery plus an inverter with an over discharge protection circuit

The Energy Kiosks are managed by a single shopkeeper who has been trained to be able to sufficiently maintain the devices as well as competently manage our kiosks. Students from the Kigali Institute of Science and Technology (KIST), a local partner university, as well as the Belgian Technical Cooperation (BTC), conduct regular checks at our Rwandan kiosks. (e.quinox 2011)

2.4 Summary other BCS's

From these examples it can be observed that other African countries share similar characteristics with Mozambique in the energy sector. There is no need to "re-invent the wheel", for the design of a battery charging station the next points should be taken into account:

- Battery charging stations is a concept that is not restricted to only charge batteries; it is also possible to **charge cellphones and lanterns**.
- **Flat rate per charge.** In most of the cases the BCS operate under a "fix rate" payment per charge.
- **Private operators** are selected in the community to run the battery charging station. The desired characteristics of an operator is ownership of an existing shop, and capital to pay for the investment cost of the BCS and experience in sells and clients.
- **Technical training for the operator.** To assure a high performance of the BCS, its necessary to explain to the operator how the BCS works as well as basic troubleshooting information.

3. Energy Demand

This chapter describes the present energy situation in Manica province, the energy services demanded as well as the current technologies used. A description of the monthly energy expenditures an average household is determined.

3.1 Energy demand in Mozambique

The battery charging station should respond to the energy service that people want. These conditions set the guidelines for an optimal design of battery charging stations.

Is important to know:

- Monthly expenditure of people in energy related services
- Potential willingness to pay for energy services and actual market prices
- Electrical appliances that the people posses or can afford to buy

To respond to these questions a study from RWI in Mozambique (Gunther 2010) is used and complemented with a small survey that I personally performed.

3.2 RWI Baseline study GIZ Mozambique

In 2008, the Rheinisch-Westfälische Institut für Wirtschaftsforschung e. V. RWI Essen conducted the study “Energy usage and socio-economic conditions in Mozambique”. This study is a baseline survey for 2 electrification projects implemented by GIZ in Mozambique, Matola with grid densification component and Chua with pico micro hydro systems and maiz mill rehabilitation.

Since Chua is located in Manica the results of this baseline survey in the energy component will be used to describe the actual socio economical condition of the province. The relevant results from this questionnaire are:

Monthly expenditures per household:
-Energy = 170 Mt/month
-Telecommunication = 140 Mt/month

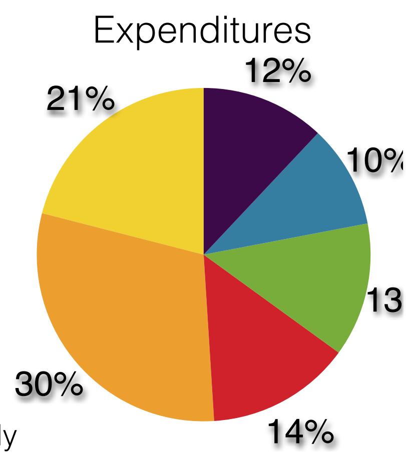


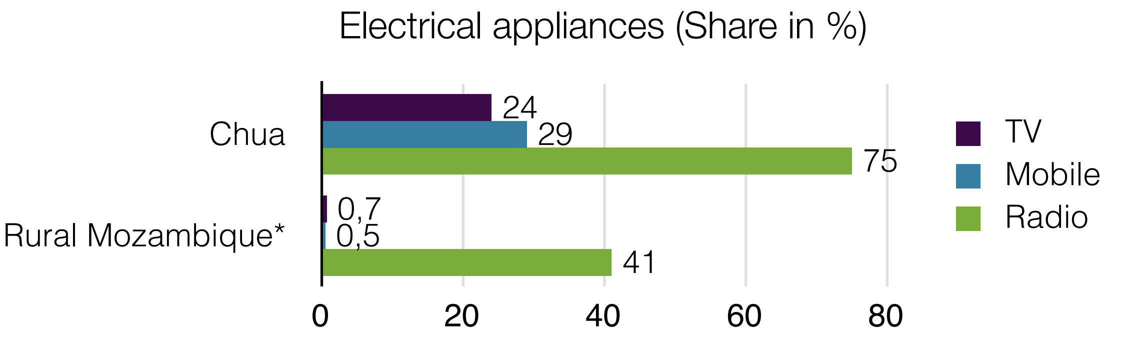
Figure 12: Results RWI study
Source: (Gunther 2010)

Regarding the usage of traditional energy sources 5 categories are described in Table 7. For lighting there are 3 different options, candles, kerosene and torches, being candles the more popular and expensive solution.

	Candles	**Kerosene**	**Batteries for torches**	**Batteries for radio**	**Wood**
% among all the households	82	51	11	45	92
Average monthly consumption	19 pieces	1.9 l	7.3 pieces	12.9 pieces	11.8 bunches
Average monthly expenditures Mt	**110**	80	55	**90**	3

Table 7: Usage of traditional energy sources
Source: RWI (Gunther 2010)

For those households that have access to electricity the most popular appliances are TV, Mobile phone and Radio. Figure 13 compares the results from RWI in Manica province with the values from the INE in rural Mozambique in share in % of the people interviewed. RWI states that the data from INE 2004 is outdated and this become evident for example in the % of cellphones.



** Data from the last household living conditions survey INE 2004*

Figure 13: Electrical appliances RWI
Source: (Gunther 2010)

One of the limitations of this study is that the categories energy and telecommunication are not described and it is not possible to know what they include.

It can be assumed that energy category accounts for the energy for lighting and cooking, but the share of each is unclear. In the same way telecommunication category is confirmed by TV, Radio and Cell phone.

This study does not account for the expenses of charging cell phones, a common practice in rural Mozambique. To get an estimation of how much a household pays for charging its cellphone per month, a small survey was performed.

3.3 Own data collection

With the aim to describe the monthly energy expenditures of the people in rural Manica, determined how much they pay for getting their cellphone charged, an alternative study was prepared. The idea was to interview households in 10 different rural communities of Manica province.

The interviews were conducted in Portuguese without a translator and they usually lasted 15 mins (the questionnaire in Portuguese and English can be found in the Appendix).

The households were selected randomly in Manica province in villages with the following characteristics:

- No connection to the national grid
- Cell phone coverage
- Road access

Due to time and resource limitations this study was not completed. At the end of my stay 15 households were interviewed in 2 different rural communities in Manica province, Vanduzi and Chimukono.

Being aware of the limitations of this study, especially the small sample size the main findings are summarized:

- People spend in average 40 Mt/month for getting their cell phone charged in a local shop. This amount corresponds to charging the cell phone once a week and paying the standard tariff of 10 Mt/service (which seems to be an informal agreement in the region).

- Torches powered with alkaline batteries are the most popular lighting method. Such devices can be purchased in local shops for around 150-350 Mt and the set of two battery for a 8 Mt.

The monthly expenditure in energy can be complemented with the expenditure for cellphone charging. Then 170 Mt/month+ 40 Mt/month = **210 Mt/month.**

Figure 14: Vanduzi and Chimukono map
Source: Google earth

4. System design

This chapter provides a technical and economical analysis of the feasibility of battery charging stations in Manica province. It answers the question: “Are BCS technically and economically feasible in Mozambique?” For the technical part the energy losses and for the financial a cash flow and NPV analysis are performed.

As shown in chapter 2, there are many different configurations for battery charging stations with different sizes and powered by different energy sources, etc. Base on these options this study analyses :

Option1: Solar business system SBS

Is a SHS (120 Wp) plus PUE like charging cellphones, charging lanterns, barber shop , cinema[4], etc

Option 2: Solar battery charging station SBCS

Is a solar stand alone system for starter battery charging

Option 3: Micro hydro power battery charging station MHP-BCS

For starter battery charging

Two different options of solar system are presented:

SBS-Smaller installation (120 Wp) for self consumption and PUE

SBCS-Battery charging station for starter battery charging 600 Wp.

The goal with this is to determine which size of installation is more suitable for the local conditions in Manica province.

Finally, battery charging station powered by electricity from the mini grid of a pico/micro hydro power plant are specially interesting because Manica province has great pico/micro hydro power potential and some micro hydro power plants are being constructed in the next years.

The Table 8 presents a summary of the different setups from the technical and economics issues, as well as, operator and user perspectives.

Technical: Discuss the different size of the components and the electricity generated per each system. Unit potential for PUE and battery charging.

Economics: Calculation of the NPV value of the different options after 10 years assuming the operator pays 100% of the investment cost and a discount rate of 15%.

Operator: Service provided, self consumption and role from the operator.

Costumer: Tariff paid for the services according to the maximum monthly expenditure in energy , as well as role and number of beneficiaries.

[4] Use a TV set to play a movie For more information refer to the section 4.1.2

	SBS	SBCS	MHP+BCS
Technical			
PV Module [Wp]	120	600	--
Shortest Lifetime	3 years battery	3 years battery	3 years battery
Electricity [kWh/yr]	78	388	372
Maximum capacity units/week	42 Mobile phones 42 haircuts Play 1 movie	9 batteries	7 batteries
Economics			
Investment cost	26 664 Mt 952 US$	129 300 Mt 4 618 US$	47 340 Mt 1 744 US$
Fee per service	Mobile: 10 Mt/0.35 US$ Haircut: 10 Mt/0.35 US$ Movie: 5 Mt/ 0.17 US$	Battery 50 Mt/charge 1.7 US$	Battery 50 Mt/charge 1.7 US$
Estimated NPV 10 yrs [Mt/US$]*	88 320 Mt 3 150 US$	-149 834 Mt -5 350 US$	-47 138 Mt -1 680 US$
Operator			
Personal consumption	Mobile phone DC light Radio 100 Wh/day	Mobile phone DC light Radio 100 Wh/day	Mobile phone DC light Radio 100 Wh/day
Service offered	Mobile phones Barber shop Cinema	Lead acid starter batteries charging	Lead acid starter batteries charging
Operator role	Charge cellphones. Cut hair in the barber shop. Get DVD Movie´s.	Management of the BCS Charge the batteries Replacement of the batteries Maintenance of the batteries: Clean the poles	
Costumer			
Cost for the costumer	2.7 Mt/Wh 0.1 US$/Wh	0.09 Mt/Wh 0.003 US$/Wh	0.09 Mt/Wh 0.003 US$/Wh
Balance price (NPV=0)		0.40 Mt/Wh 0.015 US$/Wh	0.16 Mt/Wh 0.005 US$/Wh
Role	Bring his mobile and charger.	Take care and return the battery.	
Beneficiaries** hh/EnDev	50/1	10/7	8/5

**See sensitivity analysis of the NPV in the section 5.*
*** Beneficiaries hh= total number vs EnDev= applying counting rules from Table 4.*

Table 8: Different options for battery charging

4.1 Options description

The options presented offer different energy service levels from minimum to basic and therefore are not directly comparable . The aim of this analysis is to show three different options for providing access to modern energy services to the people in the rural areas in Mozambique.

Two different size solar system are compared, one is for low energy consumption applications such cell phone charging (SBS) and the second one is for battery charging (SBCS).
Two different options for battery charging are compared, one powered by solar energy and the other by electricity from a micro hydro power plant.

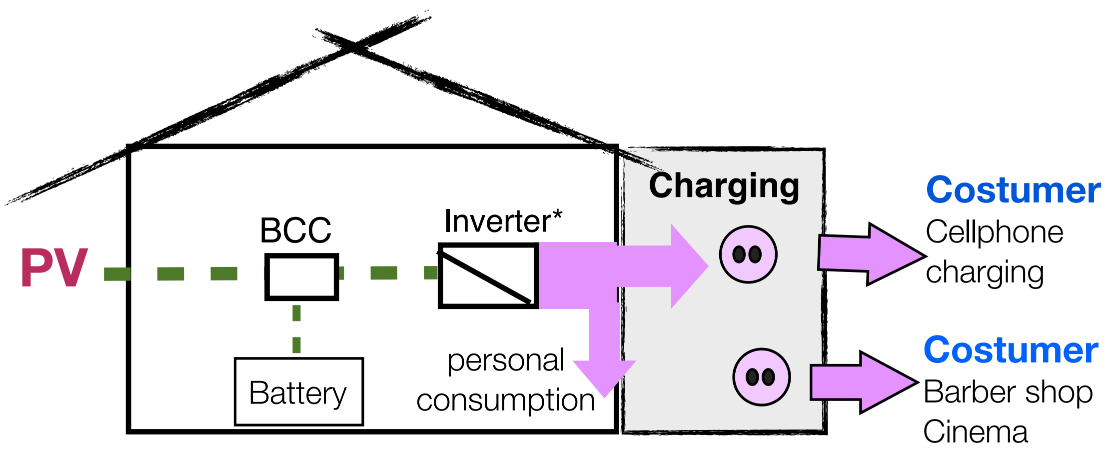
In all the cases the same amount of energy is assumed to be self-consumed by the operator to cover his own needs.

4.1.1 Solar business system SBS

Is a "household size" solar home system (120 Wp) which allows the user to perform productive use of electricity PUE.

This system will cover the basic energy self consumption of the operator (Light, Radio and cell phone charging) plus a day operated low power productive use of electricity, this includes:

- **Cell phone charging**, increasing demand for the service in remote areas. Use a conventional AC charger or if possible operate a DC charger, similar to the one that is used in car chargers (DC-DC converter).
- **Barber shop**, it has been reported that the people need to travel to big cities to get a haircut, using a conventional electric shaver a barber shop can be started.
- **Cinema,** use a TV and a DVD to play movies. Then users would pay per movie like in the cinema.



** Ideally use DC appliances to avoid the use of an inverter.*
Figure 15: SHS + PUE setup

In Mozambique solar components are very expensive and therefore they are hard to afford for average households. By including productive use of electricity an extra source of income would help them to pay for the system.

Battery charger configuration

The options are either to connect the battery of the solar home system and the battery to be rented to the same battery charge controller or to have a separate battery charger for each battery;.

EnDev Mali BCS utilized the battery charger from Steca PL 2085. This charge controller is specially design to charge independently eight different batteries at the same time. Technically the experience of this battery charger was satisfactory. Unfortunately this model is discontinued. From the retailers components list a similar charge controller from Steca of 20 A can be purchased in S&S Beria for 15000 Mt.

The recommendation is to have a charge controller able to charge more than one batteries in parallel, as shown in Figure 16:

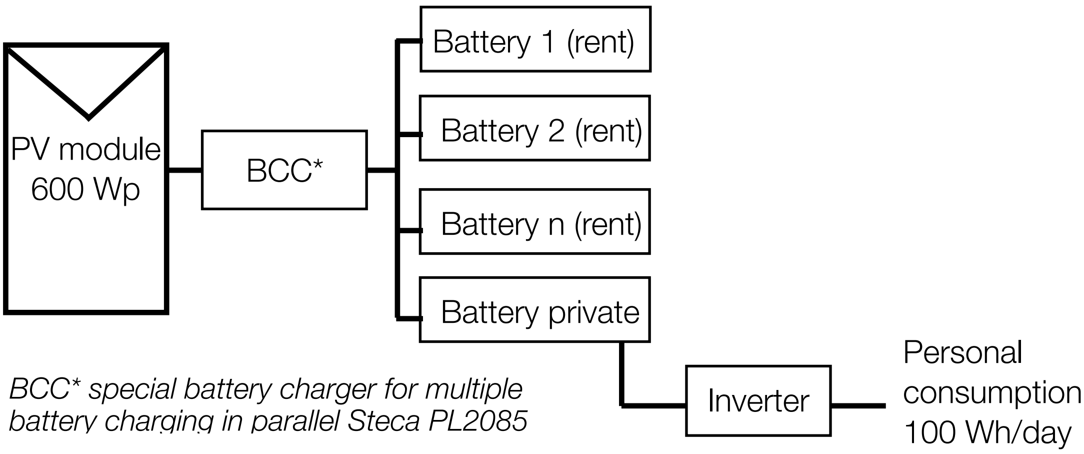


Figure 16: Battery charge controller in the SHS for PUE
Source: (Holtrof 2012)

4.1.2 Solar battery charging station SBCS

The main purpose of this installation is to charge starter batteries, conventional lead acid car batteries.The installation is a solar stand alone system big enough to generate energy to charge batteries and to cover the operators own electricity needs.

The fully charged batteries are going to be rented to the costumer for a fixed fee per charge. Additionally a deposit for the battery will be paid and a contract signed.

The advantages of the operator owned batteries are:

- Batteries will be complemented with an over discharge protection circuit and a safety box.
- Batteries can be collected at the end of the lifetime and recycled. Potentially a battery manufacturer could offset the price of the empty battery when buying a new battery (For example, battery world Zimbabwe).
- Batteries will be the same model and will be operated under similar conditions. It is more likely they will provide a similar energy service than when different batteries are charged.

The disadvantages are:

✘ High investment cost.
✘ Costumers don't take care of the battery.
✘ Battery stealing.

4.1.3 MHP batteries charging station

From the electricity produced in micro hydro power plant a battery charging station can be operated. Directly connecting an AC battery charger batteries can be charged.

The operator of the battery charging station would pay a monthly fee to the operator of the MHPP. Then the investment cost is lower but the operational cost is higher compared with the solar operated battery charging station.

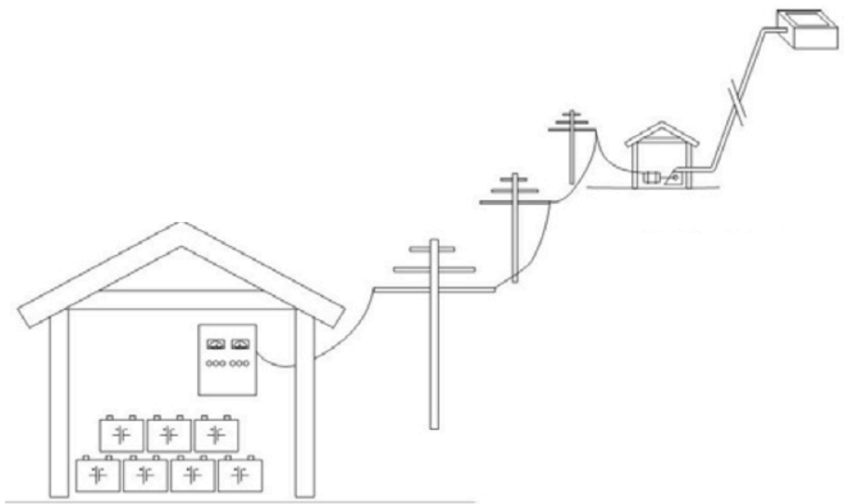


Figure 17: MHP Battery charging station
Source: (Hermann 2006)

This battery charging station is the same concept as the solar battery charging station, regarding the business operational model of the batteries, the operator of the charging station owns the batteries and rents them to the costumers.

4.2 Technical issues

Battery charging systems will be optimized to meet the load requirements of the self consumption and the productive use of electricity at the lowest price possible. A comprehensive analysis of the components is performed, as a result a recommendation of the optimal size of each system to balance the capacity and the potential share of productive use of electricity is given.

Special attention is given to batteries, different technologies, charging and discharging process and recommendation for the operation are covered in this section.

4.2.1 Battery: Terminology and Definitions

A compendium of relevant battery definitions for this study is presented (Dunlop 1997):

Ampere-Hour (Ah):
Is a common unit of measurement for a battery's electrical storage capacity, obtained by integrating the discharge current in amperes over a specific time period. For example, a battery which delivers 5-amps for 20-hours delivered 100 ampere-hours.

Capacity:
A measure of a battery's ability to store or deliver electrical energy, commonly expressed in units of ampere-hours. Capacity is generally specified at a specific discharge rate. The capacity of a battery depends on several design factors including: the quantity of active material, design and physical dimensions of the plates, and the electrolyte specific gravity.

Operational factors affecting capacity include: the discharge rate, depth of discharge DOD, cut off voltage, temperature, age and cycle history of the battery.

Depth of Discharge (DOD):
The percentage of capacity that has been withdrawn from a battery compared to the total fully charged capacity. When the battery is full the DOD is 0 and when empty the DOD is 100%.

State of Charge (SOC):
The amount of energy in a battery, expressed as a percentage of the energy stored in a fully charged battery. Discharging a battery results in a decrease in state of charge, while charging results in an increase in state of charge.

Secondary batteries:
Are the so called rechargeable batteries, the most common types are Lead Acid batteries, Lithium ion and Nickel metal batteries.

4.2.2 Lead acid batteries

Can be found in rural electrification projects, automobile and other vehicles.

Lead acid batteries can be classified as deep cycle or shallow cycle. (Alliance for Rural Electrification)

Deep Cycle batteries

> Designed to be operated at different SOC during long periods of time, therefore these should be considered for off-grid applications. These batteries are designed to provide energy to the systems during the night or on cloudy days.

Shallow Cycle

> Batteries designed for power applications, give a lot of energy in a short period of time. Also referred to as automotive batteries, are not appropriate for renewable energy applications.

A 12-Volt flooded lead acid deep cycle battery can be cycled approximately 600 times at 50% depth of discharge (DOD) at 25 C. Under the same conditions a shallow cycle battery (FLA, AGM or GEL) may last only 100 – 150 cycles.

Shallow cycling batteries are unfortunately often selected for their initial low prices, but are actually not cost-effective as their life term is much shorter and need to be regularly replaced. In addition, they are not really safe as when a battery reaches the end of its life suddenly, they are prone to shorting cells, which may lead to severe system damage.

Comparing the cost per cycle, deep cycle batteries have a much lower cost than the one of automotive batteries, unfortunately in the market in Mozambique is difficult to find deep cycle batteries.

4.2.3 Lithium ion batteries

Can be found in Pico PV systems, cellphones and consumer electronics.

The nominal voltage of an individual Li-ion cell varies between 3.2V and 3.8V, depending on the choice of the cathode material. When the battery is being charged, the Lithium atoms in the cathode become ions and migrate through the electrolyte toward the carbon anode where the combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge by applying a current.

The main advantages of Li-ion batteries are:

✔ High energy density
✔ High efficiency (near 100%)
✔ Long cycle life (>3,000 cycles at 80% DOD)

✔ Low self discharge
✔ No memory effect
✔ SOC & SOH indication. (Alliance for Rural Electrification)
✘ The main disadvantage is the high cost.

A very promising type of Li-ion battery the **lithium iron phosphate ($LiFePO_4$)** battery. This battery uses LiFePO4 as a cathode material, hence its name.
The main advantage is a longer cycle life. This type of batteries can be found for example in products from Fosera.

4.2.4 Nickel-based batteries

Can be found in portable electronics and PicoPV systems.

Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH) are advanced, easy to charge and robust battery technologies.

Ni-Cd battery technology:
✔ Extremely high electrochemical robustness and high mechanical robustness.
✔ Usable at extreme low and high temperatures from -50°C up to +60°C
✔ Chargeable with high currents
✘ Cd toxicity
✘ Memory effect

Ni-MH battery technology:
✔ Long Life
✔ Good mechanical abuse resistance
✔ No corrosive vapors given off
✘ High self discharge (Batteryuniversity 2010)

In a typical PV rural off grid application, Ni-Cd shall provide 8.000 cycles at the typical daily DOD of 15 to 20%. Ni-MH can provide 6.000 cycles in the same conditions. (Alliance Rural Electrification --)

4.2.5 Battery charging and discharging

Charging is the process of applying a positive current to the battery to reverse the chemical reaction in the electrodes. After this process energy is stored in the battery.

For optimal charging, depending of the type of battery, different charging strategies are recommended. Either applying a constant current or constant voltage or a combination of both.

The charge controller selects the strategy that will optimize the charging process, maintaining the battery at the highest possible state of charge (SOC) and protecting it from deep discharge and overcharge.

The charging process is not 100% efficient, more energy needs to be put in the system than can be stored. The next table indicates the efficiency of the most common types of batteries in this field:

Battery type	Charging efficiency
Lead Acid	0.9
Li-ion	0.9
NiMH	0.75
NiCd	0.75

Table 9: Charging efficiencies
Source: (LigthingAfrica 2010)

For the design of a battery charging station its is necessary to know the real energy needed to charge a standard cell phone, solar lantern (Pico PV) and starter batteries.

The energy in the battery can be calculated as the product of the voltage and the capacity (LigthingAfrica 2010).

$$\text{Energy}_{\text{battery}}\ (Wh) = \text{Voltage (V)} * \text{Capacity (Ah)}$$

For calculating the energy necessary for charging, the energy in the battery is divided by the charging efficiency (Table 9):

$$\text{Energy}_{\text{charging}} = \frac{\text{Energy}_{\text{battery}}}{\eta_{\text{battery}}}$$

$$\text{Energy}_{\text{charging}} = \frac{\text{Voltage (V)} * \text{Capacity (Ah)}}{\eta_{\text{battery}}}$$

The next table presents the energy required for charging the relevant appliances for this study:

	[V]	[Ah]	Type of battery	Energy charging [Wh]
Cell phone	3,60	1	Li-ion	4
Small battery	12	7	Lead acid	95
Battery 70 Ah	12	70	Lead acid	933
Battery 100 Ah	12	100	Lead acid	1335

Table 10: Calculation energy required for charging

Battery discharging

Discharging is the reverse process of charging, is the process when a battery delivers current.

Depending on the amount and type of devices connected different currents are generated. The faster the energy is drawn, or in other words, the higher the discharge current the smaller the amount of energy available from the battery.

This discharge ratio, also known as C rate, is expressed as a ratio of the nominal battery capacity to the discharge time period in hours. For example, a 4 A discharge for a nominal 100 Ah battery would be considered a C/20 discharge rate. (James P. Dunlop 1997).

4.2.6 Battery & battery charging stations

In the charging station 2 and in some cases 3 different types of batteries can be found:

- Battery of the solar home system, Lead acid if possible solar 70 Ah and 12V,
- Battery from cellphones, Li-ion 1-4 Ah
- Battery to rented to the costumer, Lead acid starter battery 70 Ah and 12 V

The battery in the SHS is protected with the battery charge controller. This will optimize the charge and discharge process and try to extend their lifetime of the battery as much as possible.(IEA 2011)

Charge controllers normally provide information about the system's performance through LEDs or/and LCD displays for simple models, and sound signals. The end-user should be trained to understand this information(Alliance for Rural Electrification)

Cellphones and lanterns already include the electronics circuits to protect the battery from overcharge and over discharge, and have a very intuitive display that shows the SOC of the battery in a graphic way.

In the case of the battery rented to the costumer an extra electronic circuit needs to be added to protect the battery and extend the lifetime . Starter batteries are designed for high power applications and not very deep discharge. Deep discharging batteries leads to irreversible damage which reduces their lifetime. In the case of lead acid batteries discharging under 20% SOC leads inevitably to a considerably reduced battery lifetime (Hermann 2006).

For this reasons the batteries need to be protected with a special electronic circuit attached to the top of the battery. This will not only protect the battery for deep discharge and but also will restrict the access to the battery pole from the user (Adelmann 2010).

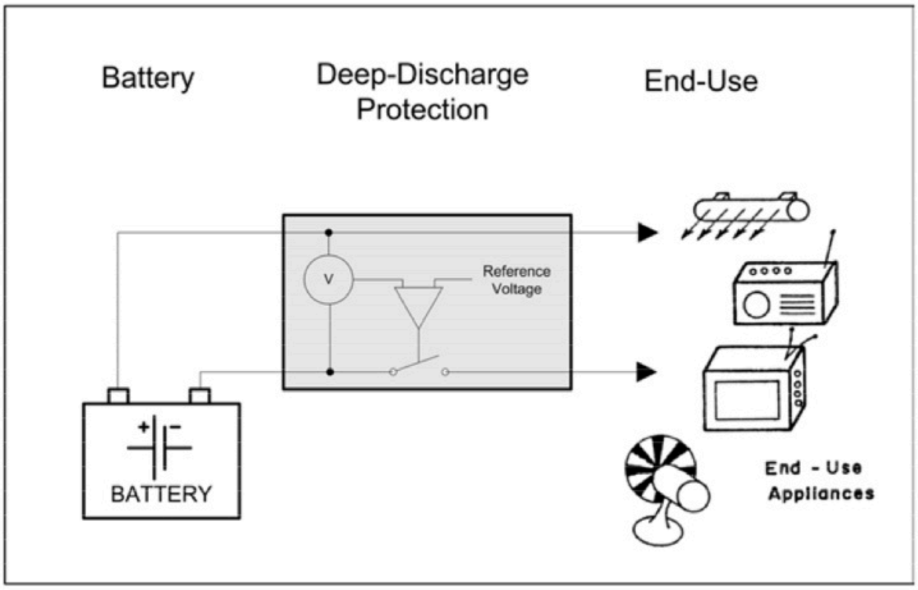


Figure 18:Diagram of the battery in the case with over discharge protection
Source: (Hermann 2006)

The capacity level of a battery can easily be approximated by measuring the battery voltage at the terminals. If the voltage falls below a predefined level all consumers are automatically disconnected by a relay. (Hermann 2006) This is a low cost deep discharge protection system, more sophisticated charge controllers can be attached but the technological feasibility needs to be considered.

This circuit will be attached to the battery by the BCS operator. The battery and the electronic controller will be contained in a sealed case that will also protect the user from any leakage or short circuit with the poles.

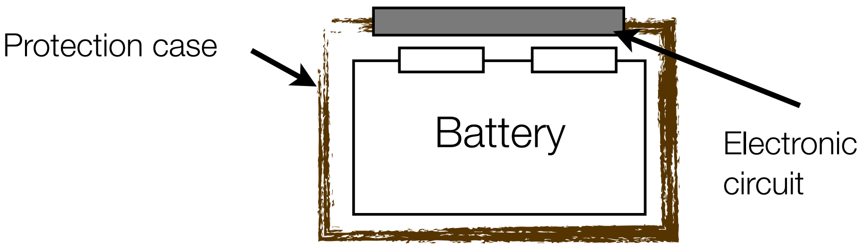


Figure 19: Battery box

Is necessary to raise awareness in the community about the importance of the over discharge protection. Nowadays batteries are completely drawn out and since the electronic circuit will regulate that the battery does not go under 80% DOD, it is not hard to think that the costumers will try to remove the charge controller to obtain more energy from the battery.

The following list present *concrete recommendations for handing lead acid batteries:*

General

- Keep the battery a cool well ventilated place, never in the sun.
- Use a battery charge controller.
- Never store the battery empty, charge as frequently as possible.
- Transport carefully.

For charging

- Allow fully saturated charge in the lead acid battery .

For discharging

- Don't cycle in a low SOC
- Avoid deep discharge using additional electronic circuits.

4.2.7 Solar powered systems

The options: SBS and SBCS are stand alone systems, whose main components are:

Solar panels: collect sunlight and convert it into electricity.
Battery Charge Controller: controls battery overcharging and deep discharging protecting it and guaranteeing longevity. At the same time it protects the load against high and low voltages.
Batteries: store energy for later use. In a SBCS is important to differentiate the battery from the SHS with the battery rented to the costumers.
Inverter: convert the energy from DC to AC[5].
Loads: are the final user of the energy that is produced.

For the operation of this systems it is necessary to differentiate between the energy demand in during the day and during the night.

DAY: PV modules produce electricity (battery charging); this is distributed among the battery and the load by the battery charge controller. The load during the day is mainly the electricity required for PUE. A small amount is used for self consumption in the shop, for example a radio.

NIGHT: the battery is the source of energy for the shop (battery discharging). Then the load is mainly self consumption (lights, radio, TV). Just in case of a very high demand is recommended to charge devices at night.

[5] Ideally the system would operate with DC appliances. It depends on the availability of DC devices in rural Mozambique.

An adequate sizing of the system is important to increase the lifetime of the components. Undersized storage capacity is one of the main technical factors contributing to a rapid decrease in battery performance (Huacuz 1995)

For the PV system sizing calculation the next steps are followed:

Step 1. Energy produced by the system.
Calculate the final energy generated considering local irradiation and system losses.

Step 2. Energy & the battery,
Calculate the energy required to fully charge the battery of the system and the time needed under the system conditions.

Step 3. Energy for personal consumption,
Account for the basic access to energy defined by EnDev in Table 4.

Step 4. Energy for PUE,
Calculate energy demanded per service and the frequency.

Energy from the sun

Mozambique is a Sun Belt country; this means has a high solar irradiation. Satellite data from RETscreen (NASA 2011) provides the monthly values of the solar irradiation in Manica (Table 11).

Chimoio is used as the example because is located in the center of the province and the irradiation data is representative of the other cities in the province.

CHIMOIO COORDINATES

Latitude -19,1164
Longitude 33,4833

Month	Daily solar radiation – horizontal
	kWh/m^2/d
January	5,73
February	5,54
March	5,32
April	4,97
May	4,59
June	4,10
July	4,27
August	5,10
September	5,58
October	5,99
November	5,86
December	5,52
Average	5,21

Table 11: Chimoio annual irradiation

This is the energy input received by a PV module in Chimoio, but not all of this energy can be converted into electricity, there are several losses in the components.

A qualitative analysis in a Sankey diagram shows the energy conversion flow from the PV module to the electricity outlet:

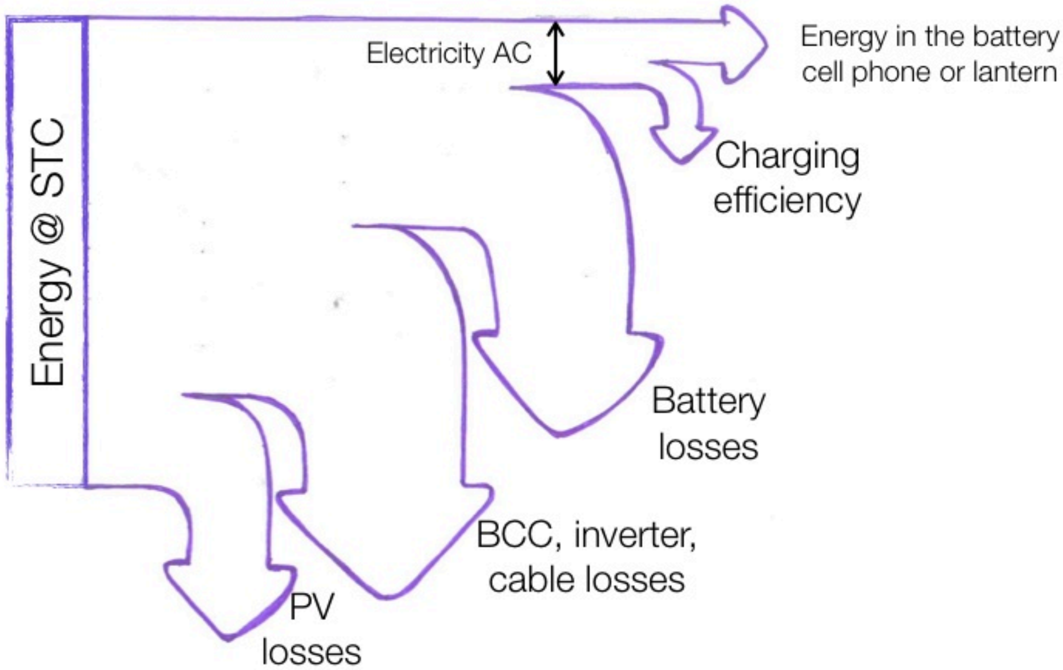


Figure 20: Qualitative analysis-Energy flow

PV modules have a rated power determined according to standard test conditions, 1000 W/m^2 and 25ºC. Every time these conditions are not met, the output energy from the PV module is different and the efficiency is than @STC.

This is consider in the PV losses the energy is calculated as follows:

$$\text{Energy}_{STC} = \frac{(\text{Installed capacity Wp})}{(1000\ \text{W/m}^2)} * (\text{Solar radiation kWh/m}^2\ /\ \text{day})$$

The output from the PV module is DC electricity, which is transported-stored-converted into AC in the rest of the system. During this process there are several types of losses (BCC, Inverter, cables and battery).

A factor that accounts for the losses mentioned in Table 12 is added to the formula.

$$\text{Energy}_{SHS} = \frac{(\text{Installed capacity Wp})}{(1000\ \text{W/m}^2\ )} * (\text{Solar radiation kWh/m}^2\ /\ \text{day}) * \eta_{sub-\text{system}}$$

Component	Efficiency
Deviation factor from STC efficiency	90%
Cables and connectors	90%
Battery*	70%
Inverter	70%
BCC	90%
OVERALL (Subsystem)	34%

**Product from charging efficiency, discharging efficiency and factor accounting for the aging of the battery.*

Table 12: Efficiencies of the SHS components

Another possibility for the system is to operate it in DC instead of having an inverter. For lighting and cell phone charging DC equipment is relative available in the market in Mozambique, but in the case of TV and DVD a deeper research needs to be done. It is recommended to operate this system only with DC, in this case the efficiency will rise to 50%.

4.2.8 Technical analysis SBS

To simplify the implementation process it is considered that all the components for the SHS are bought in one shop. It is necessary to select one retailer, and from his list of products offered set up a SHS. The next step is to evaluate how the components interact together, detect the “bottle necks”. and possibly replace this components for better suitable components from other retailers. At the end a list of the recommended components, with the size and retailer, is given.

From the list of the Solarmoz partners, Savon trading was selected because it is located in the center of Manica province in Chimoio, and has a reasonable prices (average compared with retailers is Beria and Muxungue).

For practicality all the components for setting up a battery charging station are assumed to be purchased in Savon trading, Chimoio. This will reduce the complications of dealing with many retailers and will facilitate the transportation of the components to the place.

The next table shows the characteristic of the products that Savon trading offers:

	Specification	Brand
PV module	120 Wp	Prostar
Battery	100 Ah	Prostar
Inverter	500 W	Prostar
BCC	10 A	Phocos

Table 13: Components offered by Savon trading
Source: SolarMoz (João Junior 2011)

By following the 4 steps proposed in the section 4.2.8 the system is sized.
Step 1: Energy produced by the system.
Assumptions
-Solar irradiance in Chimoio (Average) =5.21 kWh/m2/day
-Solar irradiance in Chimoio (June) =4.1 kWh/m2/day
-Size of the PV generator (Wp)= 120 Wp

$$\text{Energy}_{\text{SHS}} = \frac{(\text{Installed capacity Wp})}{(1000\ \text{W/m}^2\ )} * (\text{Irradiance kWh/m}^2\text{day}) * \eta_{sub-\text{system}}$$

$$\text{Energy}_{\text{SHS}} = \frac{120\ \text{W}_\text{p}}{1000\ \text{W/m}^2} * 5{,}21\ \text{kWh/ m}^2\text{day} * 0{,}34$$

Rounding the results:

$$\text{Energy}_{\text{SHS}} = 200\ \text{Wh/day (AVERAGE)}$$

$$\text{Energy}_{\text{SHS}} = 160\ \text{Wh/day (JUNE)}$$

The size of the PV generator can be increased in multiples of the size of the panels 120 Wp. For this calculation a single module of 120 Wp will be used. The bigger the capacity installed the bigger the energy that can be harnessed, but we cannot increase the size the system indefinitely, the system should be just big enough to cover the energy demand for charging cellphones.

Step 2: Energy & the battery
The battery offered by Savon trading is a 12 V and 100 Ah lead acid battery, with:

$$\text{Energy}_{\text{battery}}(\text{Wh}) = \text{Voltage (V)} * \text{Current (A)} * \text{time (hrs)}$$

$$\text{Energy}_{\text{battery}} = 12\text{V} * 100\ \text{Ah} = 1200\ \text{Wh}$$

$$\text{Energy}_{\text{charging}} = \frac{1200\,\text{Wh}}{0.9} = 1335\ \text{Wh}$$

With the 120 Wp panel 200 Wh of energy can be harness in one average day, then it will take 6.6-8.3 days to fully charge the battery.

$$\text{Charging time}_{Average} = \frac{1335\ \text{Wh}}{200\ \text{Wh/day}} = 6.6\ \text{days}$$

$$\text{Charging time}_{June} = \frac{1335\ \text{Wh}}{160\ \text{Wh/day}} = 8.3\ \text{days}$$

Daily charging of the battery, operational SOC, is perhaps the most important factor influencing longevity. A common mistake while designing renewable energy systems is to select a battery that never reaches a full SOC on a regular basis, this shortens the battery life. (Alliance for Rural Electrification)
Having a smaller battery it can be charged faster by the system, for example a 70 Ah[6], then:

$$\text{Energy}_{\text{battery}} = \frac{12\ \text{V}*70\ \text{Ah}}{0.9} = 933\ \text{Wh}$$

Rounding up the number counting for a low state of heath of the battery, 1 KWh is needed to fully charge a 70 Wh battery.

$$\text{Charging time}= \frac{1000\ \text{Wh}}{200\ \text{Wh/day}} = 5\ \text{days}$$

With the 120 Wp panel it will take 5 days to fully charge the battery instead of 6.6 days with the 100 Ah battery. It is better to have a smaller battery that is not only faster to charge but also cheaper, and when it is time to replace it this is an advantage.

There should be a balance between the load demand and the charging capacity to try to maintain the battery at a high SOC.

Step 3: Energy for self consumption
EnDev define a BASIC access to energy, as when a household is provided with 50 kWh/yr, which is equal to 136 Wh/day. Factoring in 25% for losses and rounding off this value **100 Wh/day.** For this study it is assumed that 100 Wh/day is the operator self electricity consumption.

One possible combination to consume this 100 Wh/day is:

	[hrs/day]	**[W]**	**[Wh/day]**
Light	5	11	55
Mobile	1	2	2
Radio	6	5	30

Table 14: Proposal consumption of 100 Wh/day

By multiplying the [hrs/day]*[W] of each row and then add them all together the total energy demand is calculated.

Step 4. Energy for PUE
From the daily energy production the energy for self consumption is subtracted and the remaining energy is the energy available for PUE.

[6] Can be purchased in ARS Maxixe

Energy available for charging =200 Wh-100 Wh=100 Wh/day

The suggested options for PUE are cell phone charging, barber shop and cinema.

<u>Cell phone charging</u>, Cellphones are brought by the users, there are some different models but in general most of them are small simple cellphones, Nokia or Samsung, black and white with lithium ion batteries.

$$\text{Energy}_{\text{charging}} = \frac{\text{Voltage (V)*Capacity (Ah)}}{\eta_{\text{battery}}}$$

$$\text{Energy}_{\text{charging}} = \frac{3.6V * 1Ah}{0.9} = 4Wh$$

<u>Barber shop,</u> the commercial electric shavers have relative small power consumption, 10 W (Wahlglobal). Assuming it takes 20 mins to complete one haircut, and that the AC electric shaver operates with an efficiency of 90% then the energy needed is for one haircut is:

$$\text{Energy}_{\text{haircut}} = \frac{\text{10 W*0.33 hr}}{0.9} = \text{4 Wh}$$

<u>Cinema</u>, with TV and a DVD a movie can be played, and a fee per person attending to the function is charged.

The energy demanded to play a movie is:

	[hrs/day]	[W]	[Wh/day]	Comment
TV	2,5	100	250	CRT 19 inches (Bluejay 2011)
DVD	2,5	20	50	Average DVD player (LBNL 2012)
TOTAL			300	

Table 15: Energy demand to play one movie

More energy that the one produced during one day by the SHS is required to play a Movie, therefore this extra energy is drawn from the battery. The question is if the 70 Ah battery is able to give this energy and recover a 100% SOC before the next movie is played?

The load demand for a week is calculated and the theoretical SOC of the battery estimated if only one movie is played per week.

From the 100 Wh destined for productive use, is proposed that 50 Wh are use to Cell phone charging and the Barber shop and the remaining 50 Wh for the Cinema.

The maximum amount of units (Cellphones or Haitcuts) per day are calculated by dividing the available energy by the energy demanded for charging a cell phone or giving a hair cut.

$$\text{Maximum capacity} = \frac{50\ \text{Wh/day}}{4\,\text{Wh}} = 12\ \frac{\text{cell phones/ haircuts}}{day}$$

These 12 units can be understood as 12 cellphones charged per day, or 12 haircuts per day or a combination of both but the sum per day needs to be 12 units. For cell phone charging this number of units per day is reasonable, since the operators of cell phone charging reporting an average number of cellphones charge per day as 6.[7]

With the 50 Wh/day destined for the Cinema, the theoretical SOC of the battery during one week is calculated.

Is important to highlight the next points:

- **Maximum demand** in a day will be: 450 Wh during the Day 2 (Personal consumption 100 Wh + Cellphone-Barber shop 50 Wh+ Cinema 300 Wh).
- **Battery capacity,** the 70 Ah battery is 840 Wh, but only 580 Wh of extractable energy per day (without exceeding the min 20% SOC), and 1 kWh is need to fully charge it.
- **Energy generated**, by the SHS under average conditions 200 Wh/day, but 160 Wh/day during the month with the worst irradiation.

Considering the worst conditions, 160 Wh/day, the SOC of the battery during one week will be:

Day	Service	Total demand [Wh]	Energy from/to the battery [Wh]	Battery SOC
Day 1	Charging Mobiles	150	+10	100 %
Day 2	Charging Mobiles Movie	450	-290	65%
Day 3	Charging Mobiles	150	+10	67%
Day 4	Charging Mobiles	150	+10	68%
Day 5	Charging Mobiles	150	+10	69%
Day 6	Charging Mobiles	150	+10	70%
Day 7	Charging Mobiles	150	+10	**71%**

Table 16: Battery weekly SOC during June

[7] Personal communication with the operators-September 2011 in Chimukono, Manica.

Playing one movie per week considering the worst month irradiation conditions does not allow the battery to recover to 100% SOC before the next movie is played, resulting that every week the battery is going to be cycling at lower state of charge. Nevertheless, this occurs on the month with the worst irradiation, if the average energy production is considered to be, 200 Wh, the battery could recover 100 SOC within a week.

The simplest solution is to get a TV which consumes less than 100 W, which is possible. Another solution is to get a bigger system, not only a bigger battery but also increase the PV installed capacity.

From the original list of components from Savon trading the next modifications have been done,

- **Battery**: Is preferred to have a 70 Wh battery, offered by the retailer in Maxixe. Raylite battery is a car lead acid battery not appropriate for deep cycles and low currents. Is recommended to have a deep cycle battery, but for the moment these batteries are not available with the Solarmoz retailers. (Raylite)

- **Inverter**: A bigger inverter accounts for a bigger self consumption, which is crucial in small off grid systems like this. The maximum power demand is 150 W, much lower than 500 W, as a rule of thumb the inverter should to be at least 20% bigger than the calculated power requirement. An inverter bigger than 180 W is appropriate for example the 350 W offered by ARS Muxungue.

The final list of the equipment for the SHS for productive use of energy is:

	Specification	Brand
PV module	120 Wp	Prostar
Battery	70 Ah	Raylite
Inverter	350 W	Universal
BCC	10 A	Phocos

Table 17: Recommendation of components for the SHS
Source: Solarmoz (João Junior 2011)

It can be concluded that despite of the convenience to buy all the components from one supplier, it is recommended to get the components from different suppliers according to the specifications from table 17.

4.2.9 Technical analysis SBCS

In this case a solar system will be used to charge lead acid batteries that are going to be rented to the costumers, refer to figure 16.

Step 1. Energy produced by the system

To directly compare the solar battery charging station with the micro hydro one the same amount of electricity needs to be provided. The tariff chosen is 31 kWh/month, which is equivalent to 1 kWh/day.

To generate this energy the size of the PV module is calculated under the worst conditions (June).

$$\text{Energy}_{\text{SHS}} = \frac{(\text{Installed capacity Wp})}{(1000\ \text{W/m}^2)} * (\text{Irradiance kWh/m}^2\text{day}) * \eta_{sub-\text{system}}$$

$$1\ \text{kWh/day} = \frac{(X * 120\ \text{Wp})}{(1000\ \text{W/m}^2)} * (4.1\ \text{kWh/m}^2\text{day}) * 0.49\ (\textit{June})$$

A PV generator of 600 Wp is needed, which can be build out of 5 modules of 120 Wp each. All the other components, battery, inverter, and BCC are the same as in the SHS for PUE.

Step 2: Energy & the battery
Battery of the system used for self consumption of the operator. As in the case of the SBS, the system would have a 70 Ah battery:

$$\text{Energy}_{\text{battery}} = \frac{12\text{V}*70\ \text{Ah}}{0.9} = 933\ \text{Wh}$$

Rounding up the number counting for a low state of heath of the battery, 1 KWh is needed to fully charge a 70 Wh battery. The next step is to calculate the time needed to fully charge the battery with the energy from the system:

$$\text{Charging time} = \frac{1000\ \text{Wh}}{1000\ \text{Wh/day}} = 1\ \text{day}$$

This charging time is acceptable, then the 70 Ah battery is acceptable for the system.

The next table shows the list of the components recommended for setting up a battery charging station powered by solar energy. The main difference with the system for PUE is the size of the PV generator and the extra charge controller for the batteries to be rented.

	Specification	**Brand**
PV module	**600 Wp**	**Prostar**
Battery	70 Ah	Raylite
Inverter	350 W	Universal
BCC (battery rent)	**20 A**	**Steca**

Table 18: Recommendation of components for the SBCS
Source: Solarmoz (João Junior 2011)

Step 3: Energy for self consumption

The same as in the SBS, 100 Wh/day are considered for electricity self consumption. Refer to step 3 of the section 4.2.8 for further information.

Step 4: Energy for PUE

From the initial 31 kWh/month, 93% of the energy is used for battery charging. This is equivalent to 29 kWh/month, with this energy the number of batteries charged per month is determined by:

$$Energy_{forPUE} = \#batteries * E_{battery} * Frequency_{charge}$$

$$\#batteries = \frac{Energy_{forPUE}}{E_{battery} * Frequency_{charge}}$$

$$\#batteries = \frac{29(kWh/month)}{X(kWh/\text{charge}) * Y(\text{charges}/month)}$$

-Calculation energy to charge one battery (kWh/charge)

The energy to needed to fully charge one battery is about 1 kWh.
In this case because an electronic circuit installed in the battery will limit the discharge to a maximum of 80% DOD (Alliance for Rural Electrification).

Also the efficiency of the charger used is considered. Similar to battery charger from BCS in Mali, Steca PL 2085, is used. The efficiency of this battery charger is 90%.

$$\text{Energy}_{\text{charging-SBCS}} = \frac{1\text{ kWh *DOD}}{\eta_{charger}}$$

$$\text{Energy}_{\text{charging-SBCS}} = \frac{\text{1kWh/batt*0.8}}{0.9}$$

$$\text{Energy}_{\text{charging-SBCS}} = \text{880 Wh}$$

-Calculation of the charging frequency (charges/month)

This is determined the available energy from the battery and the energy daily energy demand.

$$Frequency_{battery}(\text{charges}/month) = \frac{Energy(kWh/day) * (30day/month)}{Energy_{batt\_available}(kWh/\text{charge})}$$

From the rated capacity of the battery only a fraction of this energy can be used, the discharging process has an efficiency of 86% (LigthingAfrica 2010).

The maximum DOD is 80%.
The energy available for a 70 Ah lead acid battery is:

$$Energy_{batt\ available} = Capacity\ (Ah) * U(V) * \eta_{discharge} * DOD$$

$$Energy_{batt\ available} = 70\ Ah * 12V * 0.86 * 0.8\ DOD$$

$$Energy_{batt\ available} = 578\ Wh$$

This will happen only during a couple of cycles. When the battery is new the capacity is lower and need some cycles to reach the nominal capacity (formatting), then the peak stage (when this capacity is reached) and finally a gradual decay occurs, due to aging effects (Batteryuniversity 2010).

For a normal household a consumption of 100 Wh/day is considered as a basic access to energy (Raabe 2011).

$$Frequency_{battery} = \frac{100(kWh/day)*(30day/\text{month})}{578(kWh/\text{charge})}$$

$$Frequency_{battery} = 5(\text{charges}/\text{month})$$

Comparing this result with the experience of the battery charging stations installed Mali by EnDev, the system was designed for a charging frequency of 2 weeks (Raabe Tim 2010). After a couple of months of operation and evaluation of the performance reported that the BCS have also low frequentation rate (SARL 2011).

To correct for the low frequentation rate a factor of 0.8 is added.

$$Frequency_{battery} = \frac{100(kWh/day)*(30day/month)}{578(kWh/\text{charge})}*0.8$$

$$Frequency_{battery} = 4\text{charges}/month$$

The **charging frequency is assumed to be one week (4 charges/month)**, another reason why the charging frequency is not assumed less is for optimization reasons of the battery performance. Leaving the battery at a low SOC for long periods damages the battery, therefore it is recommend to take as soon as possible an empty battery to the charging station and recharge it as soon as possible.

Substituting the values the maximum number of batteries charged by the system is calculated:

$$\#batteries = \frac{29(kWh/month)}{880(kWh/charge)*4(charges/month)} = 9\ \text{batteries}$$

From the experience of the BCS in Mali it is known that it is difficult to estimate a reliable charging frequency (SARL 2011). This may be a complication for the operator because he will need to have more than 9 batteries to compensate for the people that do not return the battery on time, also a penalization fee for not retuning the battery on time will be considered.

4.2.10 Technical analysis MHPP-BCS

Micro hydro power stations deliver a constant electricity supply which is distributed in a local mini grid. During the night the energy is used for lighting but during the day something needs to consume this energy. Charging batteries is a solution not only because it can store the energy during the day but also because it helps to bring access to modern energy services to the people that are not connected to the mini grid.

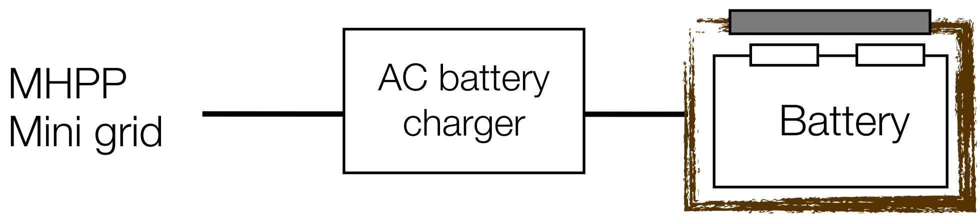


Figure 21: Micro hydro battery charging station

A micro hydro battery charging station will use electricity from the mini grid to charge batteries with a battery charger. The function of the battery charger is to convert the AC electricity to DC, manage the charging strategy and protect the battery for overcharging.

Manica has a big hydro power potential, for example in Chimukono GIZ is building a MHP where a battery charging station can be installed.

The characteristics of the community are:

- Hydro potential for installing a MHP plant
- Community not connected to the national grid, or in plans to be connected
- Demand for modern energy services
- Mobile network coverage
- Nearby households without connection to the mini grid from the MHPP.

Step 1: Energy produced by the system

The battery charging station operator will pay a fixed fee for the electricity consumed. For the evaluation of the Micro hydro battery charging stations the project in Chimukomo is going to be used as a reference:

Chimukono - Micro hydro power plant	
First draft electricity tariff- Nov 2011 (Geyer 2011)	
Electricity tariff:	Domestic consumption
	31 kWh/month, from 18:00 to 06:00 Hrs
Cost:	300 Mt/month

Step 2: Energy for self consumption
The same personal consumption as in the previous cases will be consider 100 Wh/day or 3 kWh/month and 29 kWh/month are used for charging.

Step 3: Energy for PUE

$$\# batteries = \frac{Energy_{forPUE}}{E_{battery} * Frequency_{charge}}$$

$$\# batteries = \frac{29(kWh / month)}{X(kWh / \text{charge}) * Y(\text{charges} / month)}$$

The main difference with the SBCS is the energy needed for charging the battery since in this case an AC battery charger is used. A standard AC charger is assumed to have an efficiency of 85%.(Omnitech 2012)

$$\text{Energy}_{\text{Charging AC}} = \frac{kWh * \text{DOD}}{\eta_{charging}}$$

$$\text{Energy}_{\text{Charging AC}} = \frac{1kWh * 0.8}{(0.85)} = 940 \text{ Wh}$$

In the case of the SBCS 880 Wh are needed for charging one battery and for the MHPP 940 Wh, therefore less batteries can be charged with this set up.

$$\# batteries = \frac{29(kWh / month)}{940(Wh / \text{charge}) * 4(\text{charges} / month)}$$

$$\# batteries = 7 \text{ batteries}$$

Then the MHP-BCS can support 7 batteries, charging each of them 4 times a month. Like in the case of the SBCS, is recommended that the operator would have more than 7 batteries to compensate for the delay of the costumer to bring back the battery to the station.

4.3 Financial issues

This section will compare the cost of the 3 different options in 10 years with the Net present value NPV. This indicator considers the incoming and outgoing cash flows of the project in a time frame.

Important remarks:
Is assumed that the operator pays 100% of the system cost without any loan from the Bank or a MFI.
Prices of the components is Mozambique in September 2011-Jan 2012.
The currency exchange rate 1US $ = 28 Mt[8].

4.3.1 Net present value introduction

Is a tool that compares the value of the future cash flows with the investment cost in the present. Is calculated with the next formula:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Where:
NPV=Net present value
R_t= Net cash flow
i= Discount rate
t= time of the cash flow

A positive NPV is desired, it means that the future cash flows of the project are going to be enough to pay for the investment cost and generate revenue. Following the same logic a negative number is not acceptable.

For the NPV calculation the next cash flows are considered:

OUTGOING CASH FLOWS
- Investment cost of the components
- Installation, plugs and cables
- Operation, electricity
- Maintenance, replacement of components

INCOMING CASH FLOWS
- Energy self consumption savings
- Revenue from cell phone charging
- Revenue from the barber shop

[8] Oanda (2011). "Historical Exchange rates." Retrieved 01.August.2011, from http://www.oanda.com/currency/historical-rates/.

- Revenue from the Cinema
- Revenue from the battery charging

4.3.2 Outgoing cash flows

Investment cost
From the list of the Solarmoz partners, the retailers located in Chimoio, Beira and Muxungue were selected to be the suppliers of the components for the battery charging station to reduce the transportation cost of the components. The prices considered for this study were taken from the report “Estudio Basico Sobre o Mercado PV en Moçambique” (João Junior 2011).

SBS

From the technical analysis the next list of components were recommended, plus the extra devices that need to be purchased to start with the PUE activities.

	Specification	Brand	Cost [Mt]	Supplier
Solar Home System cost				
PV module	120 Wp	Prostar	12 750	Savon trading
Battery	70 Ah	Raylite	4 500	ARS Maxixe
Inverter	350 W	Universal	1 500	ARS Muxungue
BCC	10 Ah	Phocos	1 190	Savon trading
Others				
TV	14˝	---	2000	Market Chimoio
DVD	---	---	1300	Market Chimoio
Hair cuter	---	---	1000	Market Chimoio
TOTAL INVESTMENT COST			**24240**	**$US 866**

Table 19: Investment cost –SHS + PUE

SBCS

In this case the cost are divided in the cost for the solar home system and the cost of the battery boxes.

	Specification	Brand	Cost [Mt]	Supplier
Solar Home System cost				
PV module (5 units)	120 Wp	Prostar	63750	Savon trading
Battery	70 Ah	Raylite	4 500	ARS Maxixe
Inverter	350 W	Universal	1 500	ARS Muxungue
Battery box				
BCC	20 A	Steca	1500	S&S
Battery (9 units)	70 Ah	Raylite	40500	Savon trading
TOTAL INVESTMENT COST			**125250**	**$US 4473**

Table 20: Investment cost –SHS + battery charging

MHP-BCS

In the same way, the operator is responsible for buying the batteries.

	Specification	Brand	Cost [Mt]	Supplier
AC battery charger	20 A	Steca	15000	S&S Beira
Battery box				
Battery (7 units)	70 Ah	Raylite	36 000	ARS Maxixe
Box+ protection circuit	---	---	3 600	Self manufacture
TOTAL INVESTMENT COST			**44400**	**$US 1745**

Table 21: Investment cost –MHP + battery charging

Installation cost

Percentage of the price that accounts for:

- -Installing material such cables
- -Labor, man power
- -Battery box assembling with the battery and the electronic circuit.

For the solar systems it is necessary to mount the PV module in the roof, and connect the components properly, this cost is assumed to be 10% of the components cost (material plus labor) . In the case of the the battery charging station powered with MHP this cost is included in the electricity price.

The cost of the battery box including over discharge protection circuit is assumed to be 10% of the price of the battery, this is 450 Mt, which is a realistic cost.

Operational cost

For the solar powered systems the operational cost correspond to cleaning and refiling the batteries. This can be done by the operator of the system, and no extra fee need to be paid.

For the MHP battery charging station is the cost of the electricity that the operator of the BCS needs to pay to the MHPP operator. According to the example of Chimukono, the monthly domestic tariff is 300 Mt/month.

Replacement

The lifetime of the components depends on the usage, it is complicated to predict when the components need to be replaced. Two reports that evaluate the performance of the components of SHS were used as a reference to determine the expected replacement time. The report “Life-Cycle Analysis and Optimization of Solar Home Systems” (Nieuwenhout 2001) includes a lifetime test of PV equipment and "Field performance of Lead-Acid batteries in Photovoltaic rural electrification kits" (Huacuz 1995) presents the results analysis of the performance of 555 lead acid batteries from PV kits in the field.

The assumptions of the replacement time of the components used for this study are presented in the next table. Also these values are contrasted with the warranty offered by the manufacturer of the products recommended.

Component	Replacement time	Warranty
Battery	3 years	No
Inverter	8 years	No
PV Module	20 years	25 years
Charge controller	8 yeas	6 months

Table 22: Estimated lifetime of the components

It is evident that the battery is the bottle neck of the system, from the initial investment cost of the system it is the second most expensive component, just after the PV module. The battery lifetime is highly dependable on the usage, DOD, discharge current and aging. (Gustavsson 2004)

Lead acid car batteries lifetime is reported to be 2-3 years and after this, they are replaced with second hand batteries because they are cheaper (Nieuwenhout 2001).
The problem is that the lifetime of a secondhand battery is shorter and this influence performance of the system. This problem can be avoided if the batteries are going to be owned by the operator, then he is responsible to replace the batteries for a new one that would provide the same energy service as the first one.

In contrast, when the battery is owned by the operator, one risk is that the batteries can be stolen. The BCS should operate under the principle that everyone trusts on each other. Nevertheless, is assumed that 20% of the batteries need to be replaced every year due to damaged batteries or stolen batteries.

4.3.3 Incoming cash flows

<u>Energy personal consumption savings</u>
In the energy demand section the average household monthly expenditure in Manica is described. Assuming that the operator of a BCS covers their energy needs from his own individual system, what he saves is also a incoming cash flow.

For the Radio, cellphone charging and lighting the an average user spends 210 Mt/month (7.5 US$/month):

	Mt/month	US$/month
Radio (batteries)	90	3,00
Cell phone	40	1,50
Lights	80	3,00

Table 23: Personal consumption savings

Revenue

The second source of incoming flows is the money from the service offered; this is calculated as:

$$\text{Revenue}_{monthly} = \text{Fee per service(Mt)} * \text{demand}\left(\frac{\text{users}}{\text{month}}\right)$$

To determine the fee charged per service there are 2 approaches:
-Use the same price observed in other similar business.
-Calculate the necessary price to make the NPV=0 (equilibrium price).

For mobile charging, a standard tariff of 10 Mt/cell phone was observed in the region, a similar phenomena was reported to happen in Uganda and Tanzania (Collings 2011).

For the barber shop, in Vilakulos Inhnmbane, exists a battery powered barber shop which charges 20 Mt/haircut. The barber shop is located very close to the city and the batteries are recharged by electricity from the gird.

The Fee proposed is 10 Mt per haircut. It is know that in rural areas the people can afford to pay 10 Mt, which is the price for charging a cell phone or buying a soda (coca cola).

For the Cinema in Mouha, Manica there is example of a "cinema" powered by diesel generator. The fee charged per movie is 5 Mt per adult and 3 Mt per kid.

Regarding battery charging fees in Mozambique no information was found.
The fee is expected to be:
MINIMUM: Price to pay for the investment cost in the battery lifetime .
Calculate the price that needed to be charged to make the NPV=0, in the case of the SBCS is 123 Mt/charge and in the MHP is 75 Mt/charge[9] under the moderate scenario.
MAXIMUM: Monthly energy expenditure of an average household 210 Mt/month.

The price for the solar battery charging station should be in the range:
Minimum: (123 Mt/charge)(4 charges/month)= 492 Mt/month
Maximum: 210 Mt/month

The price for the solar battery charging station should be in the range:
Minimum: (94 Mt/charge)(4 charges/month)= 376 Mt/month
Maximum: 210 Mt/month

[9] Refer to the section 4.3.5 for more information.

In both cases the minimum price required to pay for the investment cost is higher than the monthly energy expenditure of the people, this can be explain by:
•Short lifetime of the battery (Max 3 years)
•High price of the battery (4500 Mt)
•Low personal energy consumption (100 Wh/day lightning, radio, cellphone and in few cases TV).

Also, frequentation rate (charge/month) to battery charging station (in the case of starter batteries) is the result of the coordination of series of events. It is assumed the people will go weekly to charge the battery; they will have the time, physical strength to carry a 20 Kg battery for some kilometers and the money to pay for the charging fee.

For the calculations of the NPV the maximum price that the user can pay is considered. If the household monthly energy budget is 210 Mt/month and the battery is charged 4 times/month, the maximum price to charge is **50 Mt/charge**.

The fees proposed are summarized in the next table:

Service	Tariff	Comment
Mobile charging	10 Mt/mobile	Informal agreement of a standard price in the province (survey).
Haircut	10 Mt/haircut	Proposal (calculated)
Cinema	4 Mt/adult	Same price as an existing cinema in Mouha. (survey)
Battery charging	50 Mt/ battery	Battery of 70 Ah, from the battery charging station only. (calculated)

Table 24: Proposed tariffs

Determining the demand (users/month) is a complicated task, other BCS report that having reliable frequentation rate is a crucial factor for the success of the project (SARL 2011). A sensitive analysis of the user attendance and the price of the service is presented in the section 4.3.4.

4.3.4 Sensitivity analysis: Users attendance

The goal of the sensitivity analysis is to determine the effect of the user attendance in the final NPV of each option. Different scenarios are proposed depending on the % of the maximum charging capacity (users/month) of the system utilized:

•**Optimistic scenario or 100%** of the maximum charging capacity
•**Moderate scenario or 75%** of the maximum charging capacity
•**Pessimistic scenario or 50%** of the maximum charging capacity

Using the proposed tariffs and different scenarios of users/month the total monthly revenue is calculated.

Total incoming flows= total income+savings

		Unit	100%	75%	50%
Cellphone charging	Service fee	Mt/user	10	10	10
	Demand	User/month	200	150	100
Haircut	Service fee	Mt/user	10	10	10
	Demand	User/month	35	25	15
Cinema	Service fee	Mt/user	4	4	4
	Demand	User/month	20	15	10
	TOTAL INCOME	Mt/month	2430	1810	1190
Savings	Light, radio and cell phone	Mt/month	210	210	210
	TOTAL	**Mt/month**	**2640**	**2020**	**1400**
	NPV	**Mt**	**125657**	**88317**	**50977**

Table 25: Sensitivity analysis demand-SBS

By charging the income flow and different NPV are calculated. By reducing the users by half less than half of the initial NPV of the project is reached. The demand (users/month) has a strong influence on the NPV, and can not be directly controlled but by increasing the marketing or by having some special promotions.

	Unit	100%	**75%**	50%
Battery rental	Price Mt	50	50	50
	Users/month	36	27	18
TOTAL INCOME	Mt/month	1800	1350	900
TOTAL SAVINGS	Mt/month	210	210	210
TOTAL	**Mt/month**	2010	**1560**	1110
NPV	**Mt**	-80575	**-149835**	-134778

Table 26: Sensitivity analysis demand-SBCS

In the case of MHPP battery charging station it is specially important to operate it at the maximum capacity, because the electricity price is set according a different categories, so is the same amount per month is payed if 1 kWh or up to 31 kWh are consumed.

	Unit	100%	**75%**	50%
Battery rental	Price Mt	50	50	50
	Users/month	24	18	12

	Unit	100%	75%	50%
TOTAL INCOME	Mt/month	1200	900	600
TOTAL SAVINGS	Mt/month	210	210	210
TOTAL	**Mt/month**	1410	**1110**	810
NPV	**Mt**	-29070	**-47138**	-65205

Table 27: Sensitivity analysis demand-MHPP + battery

4.3.5 Cash flow diagrams

For building the cash flow diagrams the scenario where 75% of the capacity of the system was used.

The (-) flows are the outgoing flows and are shown as blue bars in the diagram. The (+) flow are the incoming flows and are shown as green bars.
Additionally, a yellow line indicates the yearly balance between the incoming and outgoing flows.

The NPV of each option is indicated in the right corner of the table.

For calculating the NPV the next assumptions were used:
i= 15%
t= 10 years

Interest rate, i, has a strong influence on the result of the NPV, therefore selecting it is crucial for the analysis. In 2011 in Mozambique the interest rate paid by the banks for short term deposits is around 15%, therefore it was selected as a conservative value.

The interest rate is inversely proportional to the NPV result, a bigger i generates a smaller NPV.

The time period selected was 10 years. Some solar projects are evaluated over 10 years because this is the lifetime of the PV module, nevertheless due to the changing conditions in Mozambique a shorter period was chosen.

<u>SBS</u>

Year	0	1	2	3	4	5	6	7	8	9	10	NPV
(-)	-26664	0	0	-4500	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-26664	24240	24240	19740	24240	24240	19740	24240	22740	19740	24240	**88317**

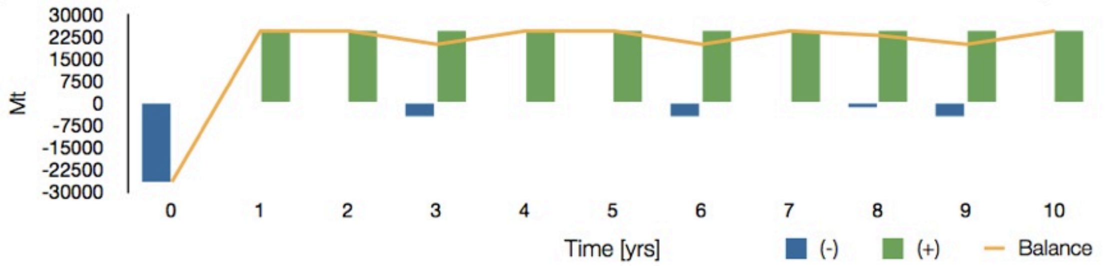


Figure 22: Cash flow SBS

From the year one the SHS + PUE will have a positive balance, even when some outgoing cash flows are presented the incoming flows will be bigger each time. Which means the operator will have the money to pay for an appropriate component replacement.

The **NPV is 88317 Mt**, which is a desired result. Represent that by investing in this project the operator would increase his capital by 88 317 Mt.

<u>SBCS</u>

	0	1	2	3	4	5	6	7	8	9	10	NPV
(-)	-129300	-4950	-4950	-39150	-4950	-4950	-39150	-4950	-6450	-39150	-4950	
(+)	0	10320	10320	10320	10320	10320	10320	10320	10320	10320	10320	
Balance	-129300	5370	5370	-28830	5370	5370	-28830	5370	3870	-28830	5370	**-149834**

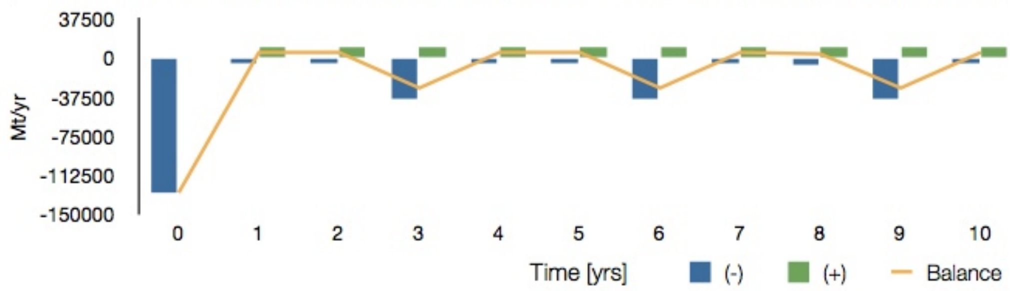


Figure 23: Cash flow- SBCS

In year 3 the operator needs to pay more than the money he has already collected in the year 1 and 2. In the model it is assumed that this money is payed but in real life when the balance of the year is negative it is not sure that the operator would have the means to pay. This negative balance occurs every 3 years when most of the batteries need to be replaced.

The **NPV is -149 830 Mt,** is not a desired result. This indicates that charging batteries is not a economically feasible option, and even less desirable than the micro hydro for battery charging station.

In the section 4.3.3 the battery charging fee was discussed, and a value of 50 Mt/charge was set as the maximum price that the households can pay.The real starter battery charging fee that compensates for the outgoing flows and make the NPV = 0 is **240 Mt/charge**.

MHP-BCS

Cash flow diagram

	0	1	2	3	4	5	6	7	8	9	10	NPV
(-)	-47340	-8,220	-8,220	-26,700	-8,220	-8,220	-26,700	-8,220	-8,220	-26,700	-8,220	
(+)	0	13320	13320	13320	13320	13320	13320	13320	13320	13320	13320	
Balance	-47340	5100	5100	-13380	5100	5100	-13380	5100	5100	-13380	5100	**-47138**

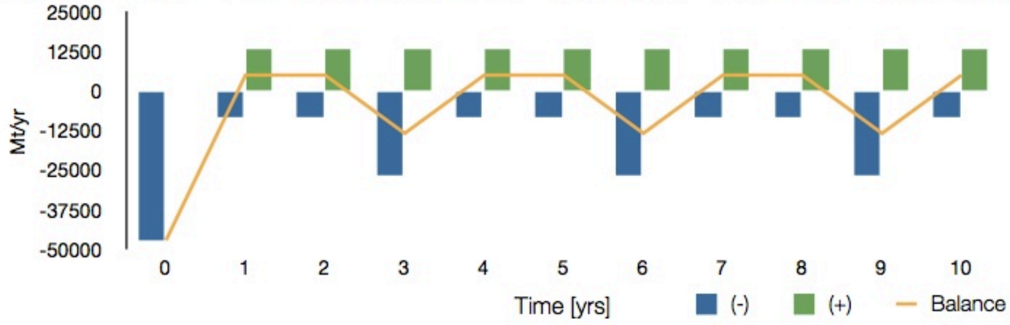


Figure 24: Cash flow- MHP-BCS

In the same way than then the solar battery charging station the balance of the flows is negative every 3 years when most of the batteries need to be replaced.

The **NPV is -47138 Mt**, not a desired result. It is smaller than the NPV of the solar battery charging station because there are less batteries.

The real price of one battery charge that compensates for the outgoing flows and make the NPV = 0 is **94 Mt/charge**.

Details of the incoming flows and outgoing flows used for each option can be found in the Appendix II.

4.4 EnDev beneficiaries

As mentioned before the different options provide a different service level and would account for different EnDev beneficiaries. By using the values of the Table 4, the number of EnDev beneficiaries is calculated.

SBS

In the case of the SHS +PUE, just the household which owns the system is considered as an EnDev beneficiary. There is no category for the beneficiaries of the PUE. Using the default value of 5 people[10] = household with the system 5 people can benefit.

$$\text{EnDev}_{\text{beneficiary}}\text{=1 SHS}(\frac{\text{5 people}}{\text{household}})\text{=5 beneficiaries}$$

SBCS

The beneficiaries of the BCS are counted as 2/3 as stated in the Table 4.

$$\text{Energy available=580 Wh}(\frac{\text{4 charges}}{\textit{month}})(\frac{\text{12 month}}{\textit{year}})$$

$$\text{Energy available=28 kWh/year}$$

This is the available energy per household and assuming 1 household=5 people
Energy available=(28 kWh/year)((1 household)/(5 people)) = 6 kWh/year

The energy covers the conditions form the partial service level.

$$\text{EnDev}_{\text{beneficiary}}\text{=9 batteries}(\frac{\text{5 people}}{\textit{household}})(\frac{2}{3})$$

$$\text{EnDev}_{\text{beneficiary}}\text{= 30 beneficiaries = 6 households}$$

MHPP BCS

$$\text{EnDev}_{\text{beneficiary}}\text{=7 batteries }(\frac{\text{5 people}}{\text{household}})(\frac{2}{3})$$

$$\text{EnDev}_{\text{beneficiary}}\text{=23 beneficiaries}$$

4.5 Preliminary results from the analysis

After performing a technical and economical analysis of the 3 different setups under the conditions before, it can be concluded that:

Technical

- If the batteries are owned by the operator, the advantage is that an electronic over discharge circuit can be included to potentially extend the lifetime of the battery. Nevertheless, is not clear exactly how this circuit can be manufactured with the current R&D conditions of Mozambique. The technical feasibility of this part is questionable.
- It is recommended to use a 70 Ah lead acid battery for the SHS and the battery to be rented. The energy generated by the PV system is enough for the operator personal consumption and the PUE assuring a high SOC of the battery at every moment.

[10] 5 households, standard value when any significant evidence of other value is provided.

- The recommended size of the components is summarized on Table 17 and Table 18.
- It is necessary to raise awareness among the users about the importance of the battery charge controller for the battery protection.

Starter batteries for rural electrification

- Designed for power applications, this means high current during short periods of time rather than low currents during long periods and deep discharge cycles. Batteries designed for deep cycling applications with longer lifetime, for example Li-ion or LiFePO4, can be found in PicoPV systems and cellphones, and this should to be preferred over starter batteries when the service provided is the same, for example for lighting.
- “High” upfront price and short lifetime when deep discharge, (For a lead acid battery of 70 Ah, 4500 Mt and max. 3 years).
- Higher energy losses from self discharge than with small batteries. (In a 70 Ah battery 1 kWh is needed to charge it, 750 Wh are stored and maximum 570 Wh should be drawn[11], half of initial energy used for charging it).

Financial

After the NPV analysis it can be concluded that:

- SHS+ PUE, also called solar business system, is potentially economically feasible option.
- Charging starting batteries, either with solar energy or electricity from the MHPP mini grid, is not financially feasible from the operators. (Calculation of the NPV after 10 years, considering 15% of discount rate)
- By promoting diverse options of productive use of electricity the financial sustainability of the project is increased. (less risk by having different source of income, challenge is organizational skills from the operator, complex, timing.
- Some PUE generate more revenues than others. The next list is a ranking of them from the most preferred to the least according to the revenue generated:

Use	Revenue (Mt/kWh)	Assumptions
Cell phone charging	2500	Fee 10 Mt, energy demand 4 Wh
Barber shop	2500	Fee 10 Mt, energy demand 4 Wh
Cinema	50-200	Fee 4 Mt/person, 5-15 persons attending each movie, energy demand 300 Wh/movie
Battery charging (Solar)	60	Fee 50 Mt, energy demand 880 Wh

[11] Maximum DOD 20%, to protect the battery lifetime.

Use	Revenue (Mt/kWh)	Assumptions
Battery charging (MHPP)	55	Fee 50 Mt, energy demand 940 Wh

Table 28: Revenue from different PUE

Revenue produced is not the only parameter considered for the selection of the type of PUE to be implemented, but I considered it to be one of the most important. It is also necessary to consider the demand of the service offered, the ways to get clients and the resources necessary to start the productive use (tools, skills necessary for example know how to cut hair, etc).

Considering this, cellphone charging is the best economically ranked (Table 28), it has high demand, good acceptance and charging a cell phone does not require any special skills, is just a matter to have right the charger.

For existing PV installations that have “surplus” energy a PUE can be performed. Keeping in mind the importance of having the battery always at a high SOC, this is controlled by the BCU.

One typical example are the governmental buildings, in Portuguese “Postos Administrativos”, which does not operate during the weekend. Then a barber shop or a cinema can be operated when there is no consumption from the governmental building.

It is necessary to keep in mind that this time where no energy is demanded from the system, the energy produced charges the battery and assures a high SOC, and this is positive for the installation.

It is recommended to evaluate in detail every specific case, the basic guidelines to calculate the energy produced are presented in section 4.2.7 and the energy consumption and revenue from PUE is presented in Table 28.

From EnDev’s counting point of view the number of beneficiaries is higher in the starter battery charging options (SBCS and MHPP-BCS). My recommendation is that the financial feasibility is prioritized.

From the operators point of view SBS is the only economically feasible option. In the case of the starter battery charger station either powered by the sun or by electricity from a mini grid of the MHPP, is not enough to financially compensate for the high cost of the installations and the batteries.

From the project point of view it need to be decided weather to increase more rapidly the number of EnDev beneficiaries at the expense of financial feasibility or not.

In conclusion, the recommendation under the assumptions of this study to start an electrification program in Manica is to promote solar business systems and productive use of electricity over starter battery charging stations.

Additional remarks for setting up a solar business system are provided in the next chapter.

5. Solar business system

This chapter provides extra information for setting up a SBS. For the operator financing options are evaluated. At the end a SWOT analysis as well as a list of the risks and mitigations for this project are presented.

5.1 Financing options

A “high” upfront cost, 26 700 Mt, is a challenge for the implementation of solar business systems, for this reason financing possibilities with Funae and commercial banks are explored.

Funae, Energy fund, is a public institution with the objective of:
“Development, production and use of different forms of low cost power as well as to promote the conservation, rational and sustainable management of power resources” (Funae 2011)

They supply financial aid and guarantees for economically and financially viable projects that are in tune with FUNAE stated objectives.The solar business system is a suitable candidate for this financial aid.

The proposal is to **lend 80%** of the upfront cost and **pay it in 3 years** at an **interest rate of 12%.** (Similar values from other renewable energy projects in Mozambique).

From the 26664 Mt, Funae will pay 80% which is equivalent to 21331 Mt and the operator will pay 6333 Mt.

The monthly payment is calculated as:

$$\mathrm{P}=\frac{\mathrm{iA}}{1\text{-}(1+\mathrm{i})^{n}}=\frac{0.01*21331}{1\text{-}(1+0.01)^{36}}=708.5\frac{Mt}{month}$$

After 3 years the cumulative payment is 25506 Mt and the total interest paid 4175 Mt. The NPV is calculated under the same assumptions that the SBS, (Discount rate of 15%, 10 years and the 75% scenario)

Year	0	1	2	3	4	5	6	7	8	9	10	NPV
(-) Funae	-21331	8,502	8,502	8,502								
(-) Op	-5333	-8,502	-8,502	-13,002	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-5333	15738	15738	11238	24240	24240	19740	24240	22740	19740	24240	**90236**

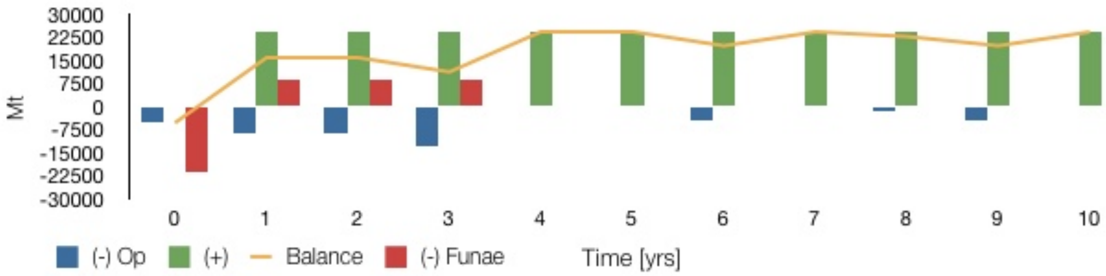


Figure 25. Cash flow-SBS - Funae

The NPV is 90236 Mt, which is even higher than when the upfront cost was paid by the operator. This is because the discount rate is bigger than the interest rate.

In the case that the is lend from a commercial bank then the conditions are (Typical conditions of commercial banks in Mozambique):

Loan for 80% of the investment cost

Pay in 2 years

Interest rate of 25%

$$P = \frac{iA}{1-(1+i)^{n}} = \frac{0.0208 * 21331}{1-(1+0.0208)^{24}} = 1140 \frac{Mt}{month}$$

The NPV is calculated with 15% discount rate and 10 years.

Year	0	1	2	3	4	5	6	7	8	9	10	NPV
(-) Bank	-21,331	13,657	13,657									
(-) Op	-5,332.8	-13,657	-13,657	-4500	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-5333	10583	10583	19740	24240	24240	19740	24240	22740	19740	24240	**87447**

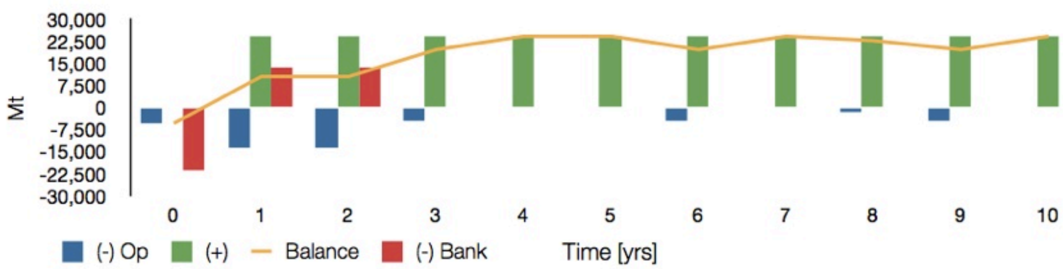


Figure 26. Cash flow- SBS-Comercial Bank

Under the commercial bank conditions the monthly payment is higher and the NPV is lower. One of the reasons is the interest, overall after the 2 years of the loan 5 980 Mt are payed just as interest in comparison with the 4 175 Mt paid for the Funae case.

The most attractive option for the operator is to borrow money from Funae because this will maximize his NPV. The procedure of how to apply for the loan and the payment mechanism needs to be further developed. The fact is that it is necessary to look for cheaper financing options than commercial banks that will help the operator to purchase a SBS.

5.2 Implementation

In short term it is important to answer the question, How to kick start a SBS in Mozambique?

The main idea is to promote the SBS as an economically attractive business opportunity for the operator, it is necessary to communicate the competitive advantages of this setup (Refer to SWOT analysis section). Also information and help to access to a cheap financing option will be provided.

To promote the systems SolarMoz workshops are key events where the SBS can be promoted among retailers and entrepreneurs. During these sessions demonstration kits can be presented and lend to the interested people, after a week if they like the system they keep it other wise they can return it free of charge.

The participants of the workshops are retailers who have the opportunity to promote the systems by themselves in rural areas. Since they receive training in basic technical skills that make them potentially qualified technicians to repair the systems.

To promote the SBS in the rural communities “Road shows” can be organized. By inviting the people for an exhibition of the system the interest is created, then the participants will have the opportunity to take a system and if they like it they buy it[12], just like during the SolarMoz workshops.

Furthermore, the operators ideal profile is a small shop owner with his own shop and with experience in running a business, and then the SBCS is a parallel business and not the main source of income. These kind of shops are found in almost every town and village, giving a wide scope for the operator selection.

In middle term, to assure the operation of the systems is necessary to:
• Procure quality of components and specially quality spare parts.

[12] This selling strategy was successful for other EnDev projects in Africa.

- Operator awareness for cleaning the panel and the poles of the battery, as well as not to disconnect the BCU.
- Qualified technical support in case of breakdown.

5.2.1 SWOT analysis

Is essential to clearly identify the strengths, weaknesses, opportunities and threats of the project to define the implementation strategies. In this case, the SWOT, analyses the situation of the SBS promoted by EnDev compared to the the existing informal cell phone charing stations.

Strengths	**Weaknesses**
Quality components. Optimal sizing of the components. Longer lifetime of the components.	Higher upfront cost compared with second hand components. Lack of technical knowledge of the operator (maintenance). Operator use the energy only for self consumption.
Opportunities	**Threats**
High demand for cell phone charging. Low electrification rate (11%).	Grid extension. Informal charging competitors. Vandalism. Misuse of the system.

Figure 27. SWOT analysis

STRENGTHS

Quality components, This can be assured by using components from the retailer partners of SolarMoz, by looking for components that offer warranty. In further stages for solar products to be sold in the SBS, PicoPV lanterns certified by Lighting Africa should be preferred over the other possibilities.

Optimal sizing of the components, Follow the recommendations of Table 17 and 18.

Long lifetime of the components,The components are new and the battery is protected with the BCU, therefore the lifetime is expected to be longer than when using second hand components.

WEAKNESSES

To over come the weaknesses the next actions are suggested:

Higher upfront cost compared with second hand components, then it is recommended to look for financing options were the money are borrowed at lower rate than the banks, for example Funae.

Lack of technical knowledge of the operator, then cooperate with participants from SolarMoz workshops, which have basic technical skills.

If the operator uses the energy for personal consumption, then inform the operator the limitations of the system (Refer to the maximum capacity of the system in Table 8).

OPPORTUNITIES
High demand for cell phone charging, Increasing number of cellphones subscriptions also in rural areas without electricity.
Low electrification rate, in Manica province 11% of the users are connected to the national grid, in the rural areas this number is even lower.

THREATS
Grid extension, Like in any other rural electrification project it is a risk that the grid reaches the community where the project is implemented. Electricity from the grid provides a higher energy service level, and if possible should be preferred.
Informal charging competitors, that the costumers prefer charge his cellphones somewhere else. By including seasonal promotions this threat can be reduced.
Vandalism, The system or part of the system could be damaged or stolen. The BCU and the battery will be well protected inside the Shop making the PV module the vulnerable part.

5.2.3 Risks and mitigation

For the implantation of a SBS for EnDev a list risks and proposed mitigation strategies are summarized in Table 29.

Risk	Description	Mitigation
Financial	Operator does not pay for the loan	Collateral
Market	Low demand	More intensive marketing
“Market spoiling”	Disappointed users	Quality products and offer warranty.
Operation	System brakes down	Training to the user, quality spare parts.
Over operation	Not enough energy for productive use of energy	Explain the user the system limitations

Table 29. Qualitative risk assessment

Financial, according to the incoming flow calculation the operator will have the money to pay for the loan. The risk is that the operator might use the money for another purpose, to assure that he will pay a collateral will be required.

Low demand, one reason is that the people do not know about the services offered in the SBS. The operator needs to do extensive marketing and offer some seasonal promotions, for example,if you charge your cell phone 10 times then the 11th is for free, to give an incentive to the people.

Marketing spoiling, when the system does not meet the service level that was offered to the user it results in disappointed users. It is necessary to be clear during the road shows about the potential and also limitations of the system

Operation, during operation the system can break down. The risk is that the system can not be repaired due to lack of skilled technicians, as a consequence the system will stop operation until someone can repair it. One possible way to mitigate this risk is by having quality components and what is specially important is having available quality spare parts.

Over operation, the so called “rebound effect”, when the operator has access to energy, this can increase his energy consumption, and reducing the share of available energy for PUE. The mitigation measurement proposed is to clearly explain to the user the capacity of the system and letting him decide between self consuming the electricity or using is for PUE.

6. Conclusion and Recommendations

The aim of this study was to evaluate the technical and economical feasibility from different set ups to start a battery charging station in the Manica province, Mozambique.

The setups compared were, a Solar and MHP battery charging stations, for starter battery charging, and a SHS plus productive use of energy, also known as SBS.

Starter battery charing stations (solar and MHP) are neither economically nor technologically feasible in Mozambique, under the assumptions of this study. The main limitation is the high price of the starter batteries and their short lifetime.

In contrast, SBS are economically and technically feasible[13], being the use PUE being one of the key strategies for making the SBS an economically attractive business opportunity.

The two options are not directly comparable because the energy service offered by a starter battery is higher than the one from the PUE presented,but when the starter battery is compared with the SBS the energy service from the SBS is higher as well.

The service level offered needs to be aligned with the service level demand, in the case of Mozambique cellphone charging is a major demand. In this case, the same service can be provided with the SBS and with the starter battery, therefore SBS is preferred.

The recommendation is to promote SBS as a business opportunity for the people in rural areas, raising awareness of the potential of PUE for income generation. Additionally quality solar components should be promoted in the SBS, such as PV systems[14], DC LED lights, DC radios whit the expectation that at some point operate the complete system operates in DC.

To kick start the project it is crucial to cooperate with the training activities from Solarmoz in order to promote the systems, find potential buyers and potential technicians. Then it is necessary to facilitate financing with cheaper options than the commercial banks, Funae being a very attractive possibility.

[13] Under the assumptions of this study.

[14] Products certified by Lighting Africa and GIZ.

For next steps is necessary to evaluate individual cases of PV systems for social infrastructure and see if there is a market for starting a low power PUE such as cellphone charging.

As an overall conclusion it can be said that SBS are a promising business option to provide access to modern energy to the people in Mozambique, emphasizing the benefits from including PUE activities. Definitely the energy service provided from PUE activities has many limitations but it is just one step to the way of electrification.

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Appendix

I. Questionnaire survey

English version	Portuguese version
MALE/FEMALE	SEXO
HOW MANY PEOPLE LIVE IN YOUR HOME?	QUANTAS PESSOAS VIVE EM SUA CASA?
MALES	HOMES
FEMALES	MULHERES
WHO GET TO DECIDE AT HOME?	QUEM E O CHEFE DA CASA?
ENERGY	ENERGIA
DO YOU HAVE ONE OF THE NEXT SOURCES OF ENERGY:	VOCÊ TEM UMA DAS SEGUINTES FONTES DE ELECTRICIDADE NA SUA CASA?
SOLAR HOME SYSTEM	SHS
PV MODULE	PAINEL SOLAR
WHERE DID YOU BUY IT?	DONDE COMPRO?
WHEN?	PARA QUANTO TEMPO?
BATTERY?	BATERIA
WHICH TYPE?	TIPO
WHERE DID YOU BUY IT?	DONDE COMPRO?
WHEN?	PARA QUANTO TEMPO?
GENSET?	GERADOR INDIVIDUAL
SIZE	TAMANHO
FUEL	COMBUSTÍVEL
LIGHTING	ILUMINAÇÃO
WHAT DO YOU USE FOR LIGHTING?	COM O QUE VOCÊ ILUMINA?
INCANDESCENT LIGHT BULB?	BOMBILLA
SOURCE OF ENERGY?	FONTE DE ENERGIA
LANTERN?	LANTERNA
SOURCE OF ENERGY?	FONTE DE ENERGIA
KEROSENE LAMP	CANDEEIRO
SOURCE OF ENERGY?	FONTE DE ENERGIA
OTHERS	COMENTÁRIO
PRICE OF ONE BATTERY?	QUANTO CUESTA UMA PILA?
PRICE OF A BOTTLE OF FUEL?	QUANTO CUESTA UMA BOTELHA(GASOLINA)?
FRACTION OF THE MONTH AFTER 100% CAPACITY	FRACÇÃO DO MES
HOW MANY HRS AT NIGHT YOU HAVE THE LIGHTS ON?	QUANTAS HORAS VOCÊ AS LIGA DE NOITE?
DEVICES AND PUE	APARELHOS & UPE
DO YOU USE THE FOLLOWING DEVICES IN YOUR HOME?	UTILIZA-SE OS SEGUINTES APARELHOS ELÉCTRICOS NA VOSSA CASA?
RADIO	RADIO
SOURCE OF ENERGY?	FONTE DE ENERGIA
HRS/DAY	HRS/DAY
FRACTION OF THE MONTH AFTER 100% CAPACITY	FRAÇÃO D0 MES
OTHERS	OTHERS
TV	TELEVISÃO
HRS/DAY	[HRS/DAY]

III. Financing options for SBS DVD	DVD
HRS/DAY	[HRS/DAY]
WHERE YOU CUT YOUR HAIR?	DONDE VOCÊ CORTA SEU CABELO?
HOW MUCH DO YOU PAY?	QUANTO PAGA?
OTHERS	COMENTÁRIO
MOBILE	CELULAR
DO YOU HAVE NETWORK COVERAGE AT HOME?	TEM COBERTURA DE REDE DE CELULAR EM CASA?
HOW MANY TELEPHONES YOUR FAMILY HAS?	HA QUANTOS TELEFONES NA SUA CASA?
HOW MUCH YOU PAY TO CALL (MONTH)?	QUANTO VOCÊ PAGA PARA TELEFONAR? (MES)
WHERE DO YOU CHARGE THE BATTERY OF YOUR MOBILE?	VOCÊ RECARREGA A BATERIA DO CELULAR EM CASA?
DO YOU CHARGE OTHER CELLPHONES?	RECARREGA OUTROS CELULARES?
HOW MUCH YOU CHARGE?	QUANTO COBRA?
HOW MANY MOBILES YOU CHARGE (DAY)?	
HOW FAR IS LOCATED THE PLACE WHERE YOU CHARGE YOUR CELL PHONE?	A QUE DISTANCIA SE LOCALIZA O LUGAR DONDE VOCÊ RECARREGA?
HOW MUCH YOU PAY TO RECHARGE THE BATTERY OF YOUR CELL PHONE?	QUANTO VOCÊ PAGA PARA RECARREGAR?
IF YOU COULD CHARGE IT IN TOWN HOW MUCH WOULD YOU PAY?	SI VOCE TIVESE POSSIBILIDADE DE CARREGAR SEU TELEFONO AQUI PAGARIA...
OPINION	OPINAO
WITH ELECTRICITY WHICH ARE THE 2 DEVICES YOU WOULD LIKE TO BUY	QUAIS SAO OS 2 ALVOS QUE. VOCÊ COMPRARIA SI TIVESE ENERGIA?
WHAT IS THE MAXIMUM PRICE YOU WOULD PAY FOR HAVING ELECTRICITY AT HOME?	QUE VALOR MAXIMO VOCE ESTA PRONTO A PAGAR POR MES PARA A ELECTRICIDADE?

II. Financial Analysis

Financial analysis - SHS+ PUE

Outgoing cash flow

	Mt	US$
PV module 120 Wp	12750	455
Battery 70 Ah	4500	161
Inverter 350 W	1500	54
Charge controller 10 A	1190	43
TV	2000	71
DVD	1300	46
Hair shaver	1000	36
TOTAL COMPONENTS	24240	866
Installation	2424	87
TOTAL	**26664**	**952**

Incoming cash flow

		100%	**75%**	50%
Cell phone	Price Mt	10	10	10
	User/month	200	150	100
Haircut	Price Mt	10	10	10
	User/month	35	25	15
Cinema	Price Mt	4	4	4
	User/month	20	15	10
TOTAL INCOME	Mt/month	2430	1810	1190
TOTAL SAVINGS	Mt/month	210	210	210
	TOTAL	2640	**2020**	1400

Quick facts:
System cost:
26700 Mt
The operator pay
100% of the system

75% scenario
Pay back time:
1.1 years

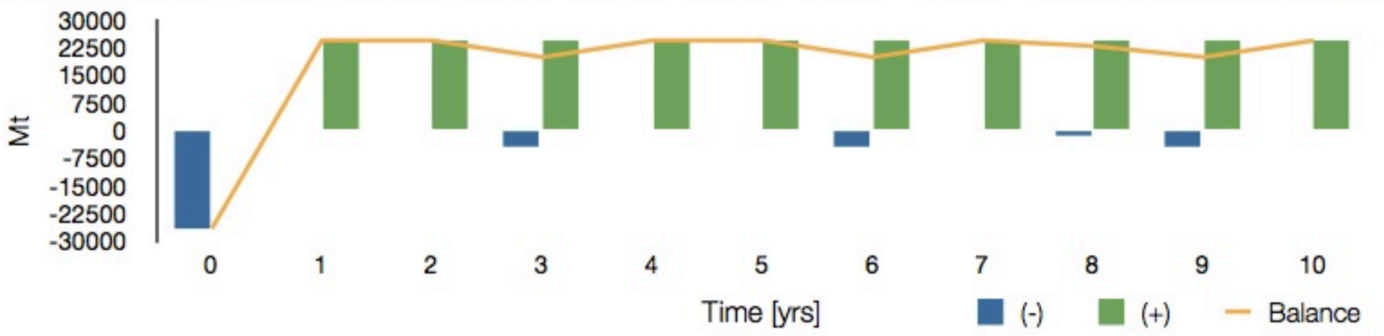
NPV = 88 320 Mt
3 150 US$

Cash flow diagrams

Year	0	1	2	3	4	5	6	7	8	9	10	**NPV**
(-)	-26664	0	0	-4500	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-26664	24240	24240	19740	24240	24240	19740	24240	22740	19740	24240	**88317**

Assumptions PUE

Time [yrs.]	10
Discount rate	15%
US$	28



Financial analysis- SBCS

Outgoing cash flow

	Mt	US$
PV module 600 Wp	63750	2277
Battery 70 Ah	4500	161
Inverter 350 W	1500	54
Battery charger	15000	536
Batteries 9 Units	40500	1446
TOTAL COMPONENTS	125250	4473
Installation	4050	145
TOTAL	**129300**	**4618**

Incoming cash flow

		100%	**75%**	50%
Battery rental	Price Mt	50	50	50
	Users/month	36	13	18
TOTAL INCOME	Mt/month	1800	650	900
TOTAL SAVINGS	Mt/month	210	210	210
TOTAL	**Mt/month**	2010	**860**	1110

Quick facts:

System cost:
130 000 Mt

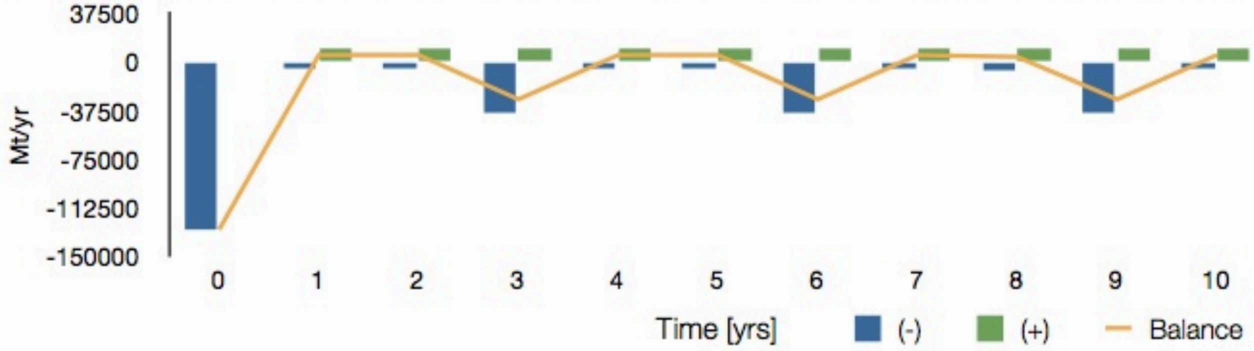
75% scenario
Pay back time:
12.5 years

NPV = -150 000 Mt
-5 350 US$

Battery price to make NPV=0,
240 Mt/charge
960 Mt/month

Cash flow diagram

	0	1	2	3	4	5	6	7	8	9	10	**NPV**
(-)	-129300	-4950	-4950	-39150	-4950	-4950	-39150	-4950	-6450	-39150	-4950	
(+)	0	10320	10320	10320	10320	10320	10320	10320	10320	10320	10320	
Balance	-129300	5370	5370	-28830	5370	5370	-28830	5370	3870	-28830	5370	**-149834**



Assumptions SBCS

Time [yrs.]	10
Discount rate	15%
US$	28

Financial analysis- MHP+ batteries

Outgoing cash flow

	Mt	US$
Battery 7 Units	29,400	1050
Battery charger	15000	536
TOTAL COMPONENTS	44400	1586
Installation	2,940	159
TOTAL	**47340**	**1744**

Incoming cash flow

		100%	**75%**	50%
Battery rental	Price Mt	50	50	50
	Users/month	24	18	12
TOTAL INCOME	Mt/month	1200	900	600
TOTAL SAVINGS	Mt/month	210	210	210
TOTAL	**Mt/month**	1410	**1110**	810

Quick facts:
System Cost:
47 350 Mt

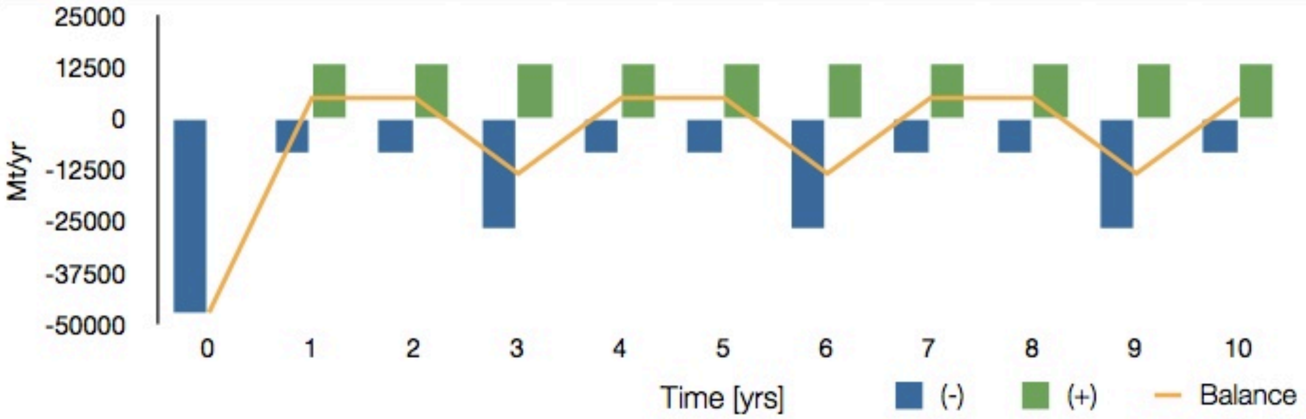
75% scenario
Pay back time:
3.5 years

NPV= - 47 140 Mt
- 1 680 US$

Battery price to make NPV=0,
94 Mt/charge
376 Mt/month

Cash flow diagram

	0	1	2	3	4	5	6	7	8	9	10	**NPV**
(-)	-47340	-8,220	-8,220	-26,700	-8,220	-8,220	-26,700	-8,220	-8,220	-26,700	-8,220	
(+)	0	13320	13320	13320	13320	13320	13320	13320	13320	13320	13320	
Balance	-47340	5100	5100	-13380	5100	5100	-13380	5100	5100	-13380	5100	**-47138**



Assumptions MHPP

Time [yrs.]	10
Discount rate	15%
Electricity Mt/month	300
US$	28

Financial analysis - SHS+ PUE (Funae lend 80%)

Investment Funae

FUNAE	Operator
21331	5333
TOTAL	26664
Monthly payment	708.5

Payment amount

P=iA/(1-(1+i)^n)

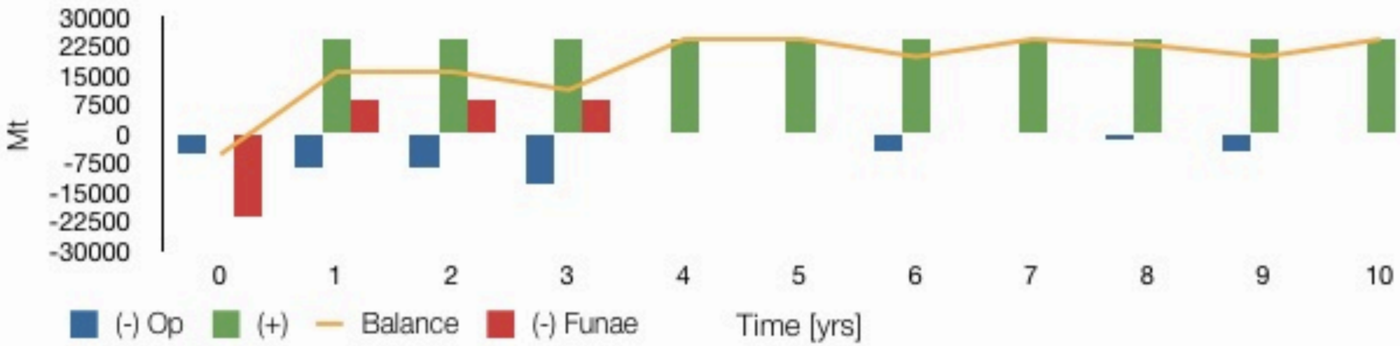
P=0.01*21331/(1-1.01^36)

P= 708.5 Mt/month

Cumulative Payments:
25,506 Mt

Total Interest Paid:
4,175 Mt

Year	0	1	2	3	4	5	6	7	8	9	10	**NPV**
(-) Funae	-21331	8,502	8,502	8,502								
(-) Op	-5333	-8,502	-8,502	-13,002	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-5333	15738	15738	11238	24240	24240	19740	24240	22740	19740	24240	**90236**



Quick facts:
What would happen if Funae lend 80% of the investment cost?
Interest rate (Funae): 12%
Pay in 3 years

75% scenario
Pay back time:
1. years

NPV = 92 236 Mt
3 290 US$

Assumptions-Funae

Time [yrs.]	10
Discount rate	15%
US$	28

Financial analysis - SHS+ PUE (Bank 80%)

Bank loan

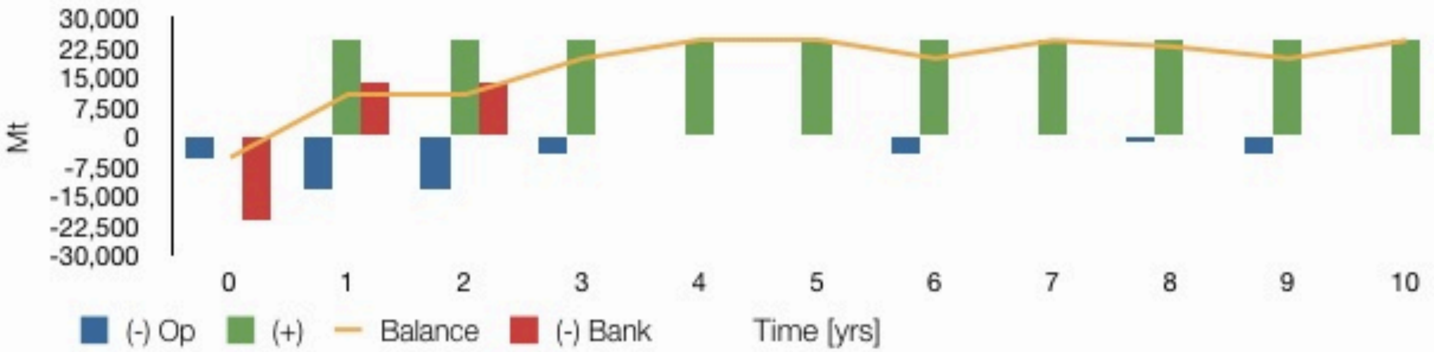
Bank Mt	Bank %	Monthly payment	NPV
26,664	100%	1,422.6	89,036
21,331	**80%**	**1,138.1**	**89,253**
13,332	50%	711.3	89,580

Payment amount

P=iA/(1-(1+i)^n)

P=0.0208*A/(1-1.0208^24)

Year	0	1	2	3	4	5	6	7	8	9	10	**NPV**
(-) Bank	-21,331	13,657	13,657									
(-) Op	-5,332.8	-13,657	-13,657	-4500	0	0	-4500	0	-1500	-4500	0	
(+)	0	24240	24240	24240	24240	24240	24240	24240	24240	24240	24240	
Balance	-5333	10583	10583	19740	24240	24240	19740	24240	22740	19740	24240	**87447**



Quick facts:
Lend money from the bank?
Interest rate (Bank): 25%
Pay in 2 years

Lend 80% of the investment cost from the bank

Assumptions Bank

Time [yrs.]	10
Discount rate	15%
US$	28