Studying the success, failure and progress of various (solar powered) rural electrification initiatives in developing nations

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I Summary

Energy poverty and the lack of access to electricity is still a big problem faced by 1.5 billion people mainly in sub-Saharan Africa and Southern Asia. The restricted access to energy brings about daily challenges and limits people's lives.
To tackle this problem many projects have been carried out and companies founded with the sole aim of improving people's lives through the introduction of sustainable technologies to the developing world. However, the development of a product or system for the developing nations, which is designed in a developed country brings many unknown problems and challenges for its developers.
This report is a literature research focusing on projects and companies working on solutions for developing countries based on solar power (PV) technology. The investigated products can mainly power LEDs and charge phones. The products can be split into three groups: portable solar solutions, solar home systems, and community based systems. The portable solar products are low power products. The solar home systems operate on a higher energy level and can therefore also power more appliances. Community based systems, which are even in a higher power range, can power villages. In this report four portable solar products, three solar home systems and two community based solutions are investigated.
It was found that solar-based energy solutions can have a high impact on people's lives by providing new opportunities, such as the ability to work extra hours when it is dark (due to electric lighting) and increase safety through enabling phone charging (enabling the possibility to contact others when danger is nearby) and ensuring there is a safe lighting solution inside the house (no more dangerous and carcinogenic kerosene lamps).
Nevertheless for a solar-based energy solution to be successful there are many important factors that have to be considered by its designers, such as: the involvement of the target customer group in order to understand their pains and needs, the target group's low income level which makes it very difficult to sell products to them in general, and the required education of the target group on electricity and how to work with solar products.
To cause a big impact on society the successful implementation of a product is required and for this it is essential to perform field research beforehand and have almost constant communication with the target group to ensure that feedback about the product reaches the developers.

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1. Introduction

1.1 Introduction to energy poverty

Energy poverty is defined as the lack of access to modern energy services. Even though the development in technology is going rapidly over the last years there are still 19 % of the world's population without or with limited access to electricity. The majority of this 19 % live in rural areas with very poor conditions in general. Therefore the access to energy, electricity in particular, could improve their lives in different ways and can give new opportunities.

The majority of people living in energy poverty are found in Sub-Saharan Africa. Also in South and South-East Asia, countries like India and Cambodia are facing a lot of poverty including energy poverty. Figure **1** shows the world map with the access to electricity. As can be seen, Africa is most affected by energy poverty.

Figure 1 Access to electricity worldwide [1]

People without access to electricity face several daily challenges. They for example have to spend lots of physical work and time to collect firewood, they have to use unsafe and environmentally unfriendly solutions for lighting, such as kerosene lamps or they cannot use their cellular phone, because they often do not have a possibility to charge it at home.

To understand the importance of the access to electricity even more, Figure **2** shows Maslow's pyramid of needs. That hierarchy shows the needs for everyone that have to be fulfilled, to reach self-esteem and self-actualization. The access to electricity can be one of the basic needs, placed into the first bottom categories. The access to electricity can increase the safety at people's homes, by i.e. replacing dangerous kerosene lamps.

[1] Source: https://wattsupwiththat.files.wordpress.com/2015/05/electricity_access.jpg

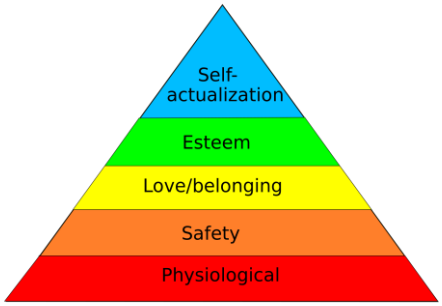

Figure 2 Maslow's pyramid of needs

1.2 Report goals & investigated projects

The lack of electricity can limit people's lives in many ways and therefore many initiatives have been started with the goal of bringing access to electricity particularly to rural areas. Over the years many projects have been carried out with new solutions for existing problems. They have all been aimed at and improving the lives of people living with an average income of just $ 2 per day through the introduction of electricity.

The goal of this report is to uncover why in the past certain projects have been successful whilst others have not. The report also tries to discover and understand trends in such projects.

Many developing countries have lots of sunlight and are close to the equator(tropical or equatorial climates), such as India and the Sub-Saharan countries. Therefore this (literature) report catalogues and describes 9 projects that have been carried out by the TU Delft and others over the last 6 years (2010-2016) that are based on photovoltaic (PV) technology and were introduced in sub-Saharan African countries, India and Cambodia.

The projects, which were considered in this report are:

- SolarNow
- SolarWorks!
- Lemnis
- Kamworks
- M-Kopa
- WakaWaka
- Onergy
- Rural Sparks
- IEEE Sunblazer

These projects each fulfil the following criteria and targets groups.

- Powered by solar
- Target customer are people in developing countries/rural areas

- Living at the base of the financial pyramid (BOP)
- Electrification of households or villages

The projects that have been investigated will be divided into 3 categories based on their size and design, in order to make better comparisons. These are:

1. Simple solar products,
2. Solar home systems,
3. Community solar solutions.

1.3 Target group & demographics

Each of the projects investigated in this report focuses on solving problems not only for the group at the so-called Base Of the Pyramid (BOP) but also for a specific location.

1.3.1 Target BOP customers and their biggest issues

The target customers/users groups of all the projects, which are described in this report, are people living at the so-called Base of the pyramid (BOP). This group is defined as that part of the population for which the money available to them is limited to $2 or less per day (see Figure **3** blue area). The group's main issue is that they are not connected to the electricity grid and in many regions with a large population belonging to the BOP there is not even a grid connection nearby, this is particularly true in Sub-Saharan Africa but generally true for all remotely located villages, far away from the towns or cities, in the developing countries. A second major problem that the BOP have is their low spending capabilities. Even though there are many renewable energy solutions and off grid systems being developed, the vast majority of the BOP cannot afford such a system as they do not have the money available to them to purchase such a system.

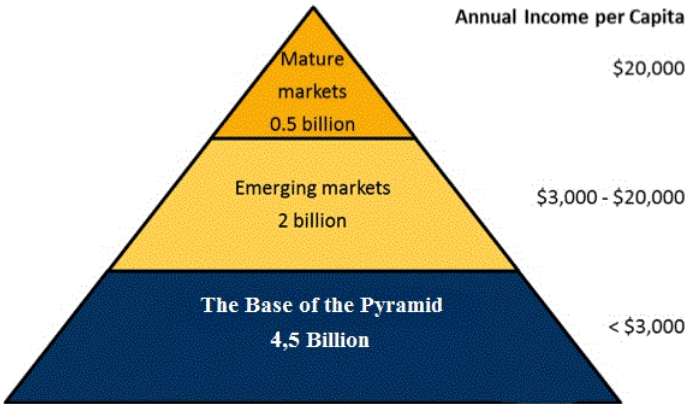

Figure 3 Worldwide income breakdown.

1.3.2 Target customer's geographical location

Each of the projects was carried out for a specific target group. Whilst all projects focussed on the BOP they also took into account the differences incurred in a geographical sense. Figure **4** and Figure **5** show an overview of the regions where the investigated projects have focused on.

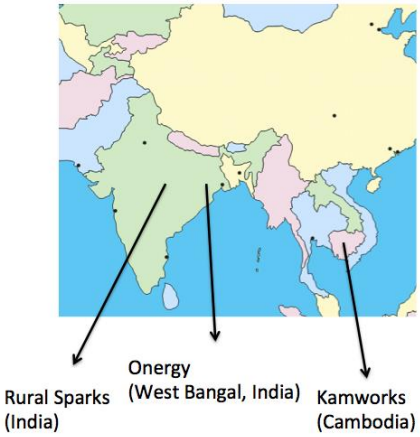

Figure 4 Projects in South Asia

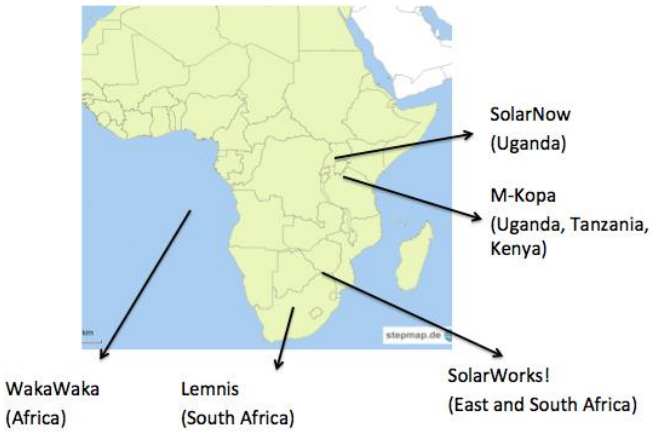

Figure 5 Projects in Africa

Focusing on the specifics of the region and target group when developing and designing a product for the improving daily life of the people in the target group is a very important step during the development and implementation process of the product. This is because the developed technology needs to be adopted by the consumer/target group, but this does not only depend on the technology itself but also on the traditions and the intricate cultural aspects that play a big role within the target community, which can greatly influence the adoption process and influence how the target group reacts to the different solutions. Sometimes the ideas that are implemented in the end do not really solve a problem for the target customer, or customers do not see the benefits of the proposed system (and thus don't use them), or they use the system for different and often unexpected purposes. This report therefore investigates not only the applied technology but also the social aspects that were responsible for the success and or failure of the projects.

1.4 Report structure

This report continues in chapter 2 with the present day solutions for lighting and phone charging, and discussing the user requirements of any system to be developed. In chapter 3 a thorough introduction of each of the projects looked in this report is given. Chapter 4 then analyses each of these projects on technical and social aspects, before analysing the customer response to the projects in Chapter 5. In chapter 6, a number of other interesting facts that arise from analysing the projects at hand are given. The conclusions are drawn in chapter 7.

2. Field Research

Many projects performed practical research out in the field. They investigated what the major problems the BOP are faced with are and how they currently solve these issues. Furthermore, they also investigated what the requirements are for simple solar products and for solar home systems to be developed for the BOP. The Lemnis project explicitly investigated what the most important issues are for the BOP. Their report with respect to these issues can be summarized as follows:

During the project, students and team members talked to the target group and found out that after lighting, the most important appliances for the consumers are the possibility to charge their phones and to power a TV.

2.1 Pre-project implementation solutions to practical problems

Prior to the development of solutions for these practical problems that the BOP experience some of the projects performed field research into what these problems are exactly. The two main problems: Lighting and phone charging are described next.

2.1.1 Lighting

The solution most of the people living without a grid connection and without access to electricity are using is the kerosene lamp. This is often the only choice people have, even though it is very dangerous (fire hazard), can cause health problems (carcinogenic, carbon monoxide poisoning) and also bad for the environment (CO2 emissions). Kerosene lamps are responsible for 400,000 deaths in sub-Saharan Africa only[2]. It has been found that on average the BOP using kerosene as a lighting solution spend about $0.20 per day on for kerosene[3].

The following is a summary from the Kamworks project with regard to lighting costs[4]
Within a project carried out by a student group, research was done to find out how much money people are paying for energy in Cambodia. Compared to other Asian countries Cambodia has one of the lowest electrification rate with only 12 % connected to a power supply[5]. But not only the access is a problem, also the existing network suffers a lot from fluctuations. However, the network only reaches people in cities and towns. In rural areas only 6 % of the population is connected to an electrical energy supply.

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[2] Overall, indoor air pollution causes around 400,000 deaths per year in sub-Saharan Africa alone. http://motherboard.vice.com/read/the-plan-to-sell-250-million-solar-lamps-to-rid-african-homes-of-kerosene)
[3] http://global-off-grid-lighting-association.org/wp-content/uploads/2013/09/kerosene_pricing_Lighting_Africa_Report.pdf
[4] student report [5]
[5] *www.cambodia.org*

The majority of people in rural areas are using kerosene lamps for lighting. Kerosene lamps are used both for inside the house but also for outside. During bad weather, the lamps cannot be used outside, which limits the use of that lighting solution. According to Kamworks, people consume about 1,5 L to 2 L of kerosene every month, where they pay about $1 per litre.

2.1.2 Phone charging

Another very important application people lacking electricity are missing is the possibility to charge their cell phones. Most people do own a simple cell phone but often don't have any opportunity to charge and therefore use it. The phone is an important device to stay in touch with friends and family, but also in many developing countries it has become a way of doing payments. Not only in Africa, but also in Asia phone banking – also known as a phone-based money transfer, financing and microfinancing service - has become common practice. M-Pesa (set up by Vodafone) is an example of a Kenyan company providing phone banking services. It is used in most of the regions and available everywhere[6].

Not only for banking in general, but particularly when bringing products such as solar home systems to rural areas, the phone banking system is an excellent way to make instalment payments and transfer money even if people have no bank account.

The following is a summary of the Lemnis project regarding phone charging. During the Lemnis project that had the goal to design a solar powered phone charging device, the students found out that most phone owners where using their phones at least three times a day, whereas it was for most of them only possible to charge the phone at their office (see Figure **6**).

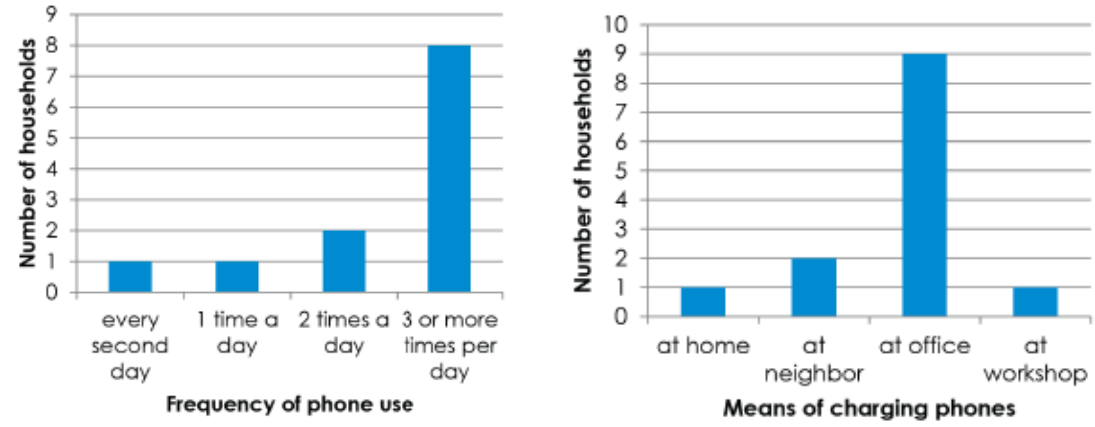


Figure 101. Frequency of phone use

Figure 102. Means of charging phones

Figure 6 Frequency of phone use and means of charging phones.

[6] http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/0,,contentMDK:22551641~pagePK:146736~piPK:146830~theSitePK:258644,00.html

2.2 Requirements for products to be developed for the BOP

In order to design a product that can replace these current solutions and therefore increase the daily lifestyle of people in rural areas without access to electricity, people were interviewed and also a time frame for when solutions are needed were found.

2.2.1 Portable solar products

SolarNow! did field research in Madagascar. Their idea was a light source powered by the sun with an integrated storage.
During the field research of different student group it could be seen, that there are conditions and lifestyles that can be seen more often. Frequently occurring personas the research groups came across during their field research could be divided into two groups with regard to their level of income. These are people with a low-income; less than € 20 a month, and people with high-income; more than € 40 per month.

Very often in the low-income category the individuals have no permanent job and therefore do not have a constant income. They often live with a big family of four or more children and need about three hours of low quality light. They also found, that people want to have a low intensity light source for during the night. Having a light during the night is supposed to keep the Vazimba[7] away. Usually people want to have light in the evening for about two to three hours.

Kamworks designed a simple solar powered portable lighting solution for Cambodia. The research to find out the requirements for the product was carried out in Cambodia. There are many requirements for the product. To find these the daily life of people was observed and analysed, to find out exactly when and for which activities a light is required.
The field research found the following requirements:

- The product should be portable (light and small) and weather resistant
- The product should provide half spherical light distribution and should give about three hours of light
- It should not give more running costs for the user
- The product should be usable intuitively
- The charging of the product should not include any third party
- The product should allow to carry and hang it
- The light output should be enable to study/read
- The product should be light and durable
- The product should be solar powered
- The product should include an educational system around it
- The product should survive common accidents while in use (e.g. falling from table, bumping into walls)

[7] The Vazimba, according to popular belief, were the first inhabitants of Madagascar. (source: https://en.wikipedia.org/wiki/Vazimba)

2.2.2 Solar home systems

SolarNow sells solar home systems in Uganda. During a student project to improve the design of the product, field research was done in order to understand the user needs and their lifestyle better. The research was done in the rural village of Kayunga where they talked to 10 people in 11 different households. The student team split the requirements of the customers into four levels of importance.

1. The most important criteria for the customers are durability, flexibility, safety and visibility. During the interview one of the customers pointed out, that he was a bit scared of the system and he did not want to touch it. Also in a school, where one of the systems was installed, the teachers did not want the students to touch it and had to find place up on a shelf such that student could not reach it.
2. Price, the size, the service provided and the cleaning required.
3. The brand and the usability.
4. The least important features are the colour and shape.

Figure **7**, depicts the results of the SolarNow research where "." Indicates the least important and "!!!" most important criteria.

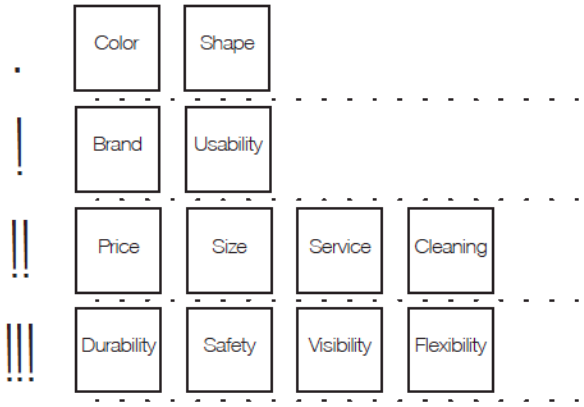


Figure 7 Important requirements for target customers.

2.3 Components for solar systems

There are 2 different types of solar systems determined by the load. Solar systems can either just supply DC power as shown in the setup in Figure **8** or only AC (Figure **9**). In case of a system with both DC and AC loads, the DC load is connected between the charge controller and the inverter. The components are discussed in this section.

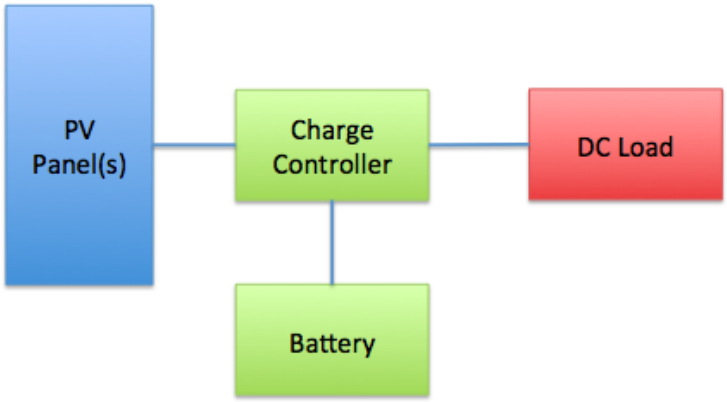


Figure 8 System setup DC solar system

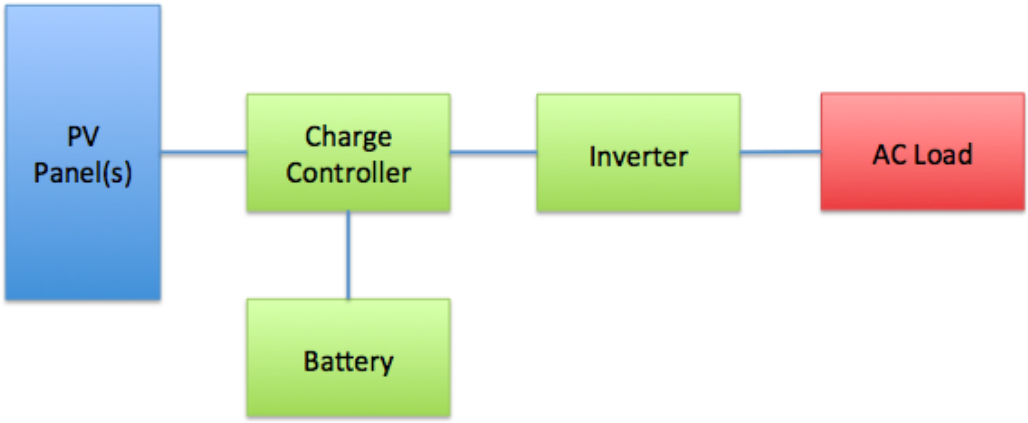


Figure 9 System setup AC solar system

2.3.1 PV module

First PV modules got introduced in the 70s and since then not only technology wise the development is growing rapidly. Also depending prices, PV panel are getting cheaper very fast. Figure **10** shows the price development since the first modules were on the market.

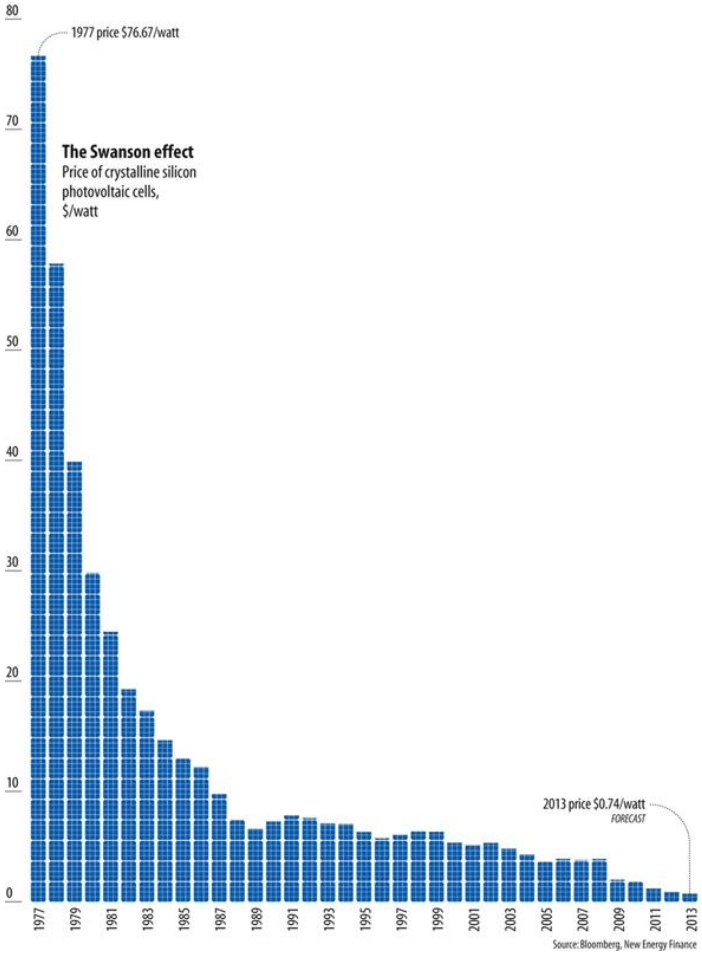


Figure 10 *PV price development since 1977 till 2013. source: cleantechnica.com*

Different PV module technologies are available on the market, which differ in price, efficiency, physical dimensions and production process. In general the technologies can be divided into wafer based silicon technologies and thin film technologies, where the wafer based solutions are again split into mono and poly crystalline. Wafer Based Silicon solar panels are the most common technologies and makes up 90 % of today's photovoltaic usage. [7] A detailed splitting of the several technologies is shown in Figure **11**.

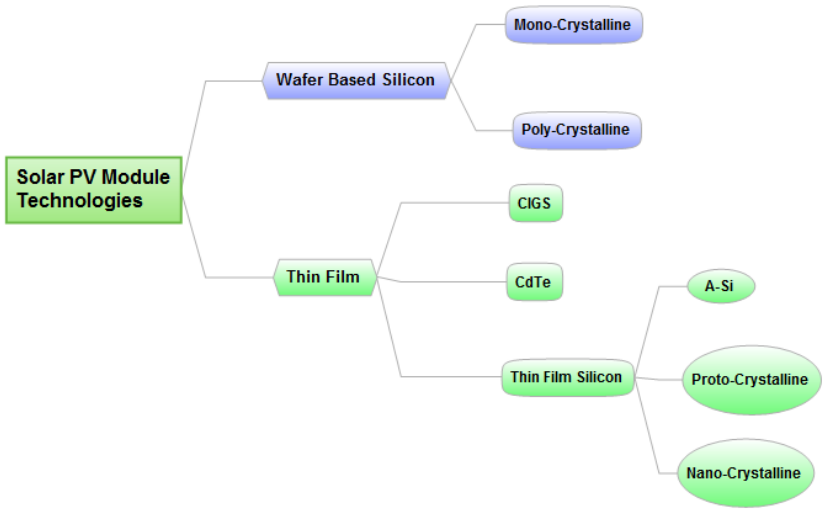


Figure 11 Solar PV Module technologies

To get a better understanding about the different technologies and the advantages and disadvantages, Table **1** shows an overview of these factors. The main factors for the selection of a PV module are very often the lifetime and efficiency, where the monocrystalline module has the highest efficiency and the polycrystalline has the easiest production and the lowest price.

Table 1 *Comparison of different photovoltaic technologies. [7]*

	Monocrystalline	**Polycrystalline**	**Thin Film**
Advantages	- Highest efficiency - Space efficient - Longest life expectations	- Production simpler and cheaper - Lower heat tolerance than monocrystalline solar panel	- Simple mass production - Look more appealing - Can be flexible - Not as sensitive to temperature and shading
Disadvantages	- Most expensive - Complete break down of circuit by shading - High amount of waste during production - More efficient in warm weather	- Lower efficiency compared to monocrystalline (13-16%) - Lower space-efficiency	- Low spacial efficiency - Degrade faster than other technologies

2.3.2 Charge controller

The charge controller is basically a component consisting of power electronics carry out four main functions:

- It powers the load via the battery and protects the battery from under charging
- It controls the charging of the battery and protects the battery from over charging
- In the case that an Maxim Power Point tracker is integrated, it can control the efficiency of the PV module (more information see [15])

2.3.3 Battery

Every solar-based system requires storage for the energy usually in form of a battery. There are many different batteries technologies available on the market for different purposes. Figure **12** shows the energy density in W/kg versus the energy density in Wh/kg. In a very small energy density range capacitors are usually used in electrical systems. For higher energy densities from about 10 to 100 Wh/kg batteries are being applied, such as Li-Ion, Ni-MH and lead acid batteries.

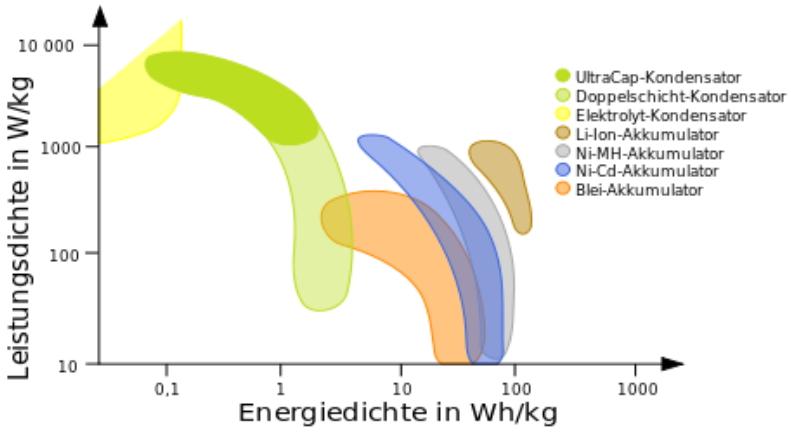


Figure 12 Power density versus energy density for different battery technologies [source: patona.de[8]]

2.3.4 Inverter

PV modules produce DC power. Therefore once a solar system has appliances that require AC power the system also needs to have some power electronics to convert the DC to AC. Costs for the converter can vary highly, depending on the system size.

2.3.5 Loads

A PV system can power different appliances depending on the size of the PV module(s) and the battery. Loads for PV system looked at in this report are i.e.

[8] picture source: http://www.patona.de/ratgeber/wp-content/uploads/2014/06/energiespeicher.jpg (last visited March 2016)

lights, phone charger and in case of higher power ranges TV and fridges. Depending on the load requirements, the system supplies DC or AC power.

3. Reviewed projects

Since there are projects/products/companies just focusing on small solar products, such as a simple portable light, or a phone charging device powered by a solar panel and others with the purpose of integrating a complete system into a house, shop or even village, the reviewed projects are separated into three groups:

1. Simple solar products: simple single function solar products.
2. Solar home systems: a solar system integrated in a single household or shop.
3. Community solar solutions: with products designed for complete villages.

The difference between the second and third category is that the third category's products power from the solar panels needs to be much higher compared to that of the solar home systems. For that reason a third group is implemented.
All information about field research and the design process are taken from student reports about the projects. If the information is not from the reports there will be another reference.

3.1 Simple solar products

SolarWorks! focus lays in the design. The first product on the market was the so-called power ball, which is a small device that can be used for lighting, but also for phone charging. In the future, SolarWorks! will also sell solar home systems, including several light bulbs installed in the house.

Kamworks designed the “moonlight”, which is a light connected to a small solar panel. The light is portable and can be hang on the ceiling or carried around.

Lemnis designed a product only for phone charging. It is a small solar panel, portable, that can be simple used wherever people need it in their daily lives. The focus was, to give people access to power in order to charge their cell phones, which is most of the time only possible at peoples work place or at friends homes, if they have electricity.

WakaWaka has two different designs. The Waka Waka light and the Waka Waka light including the possibility to phone charging. Both devices are light and very easy to carry around. WakaWaka sells its products in the developed world and the design is not just made with the only focus on rural areas, but also for the outdoor use. For every sold device in Europe, one device gets donated in a crisis-area, i.e. for refugees living in camps. WakaWaka has also founded a foundation, which donates devices to people facing crises, such as weather disaster or conflict solutions, such as war or political instabilities in the country affecting the stable energy supply. Everyone can also make a donation for devices, which are then sent to the crises areas.

Onergy is a company operating in India, selling all kinds of solar powered systems. During this work, the focus lied in solar home systems, specific in the Azad Power Pack. The Azad Power Pack is sold in different sizes, depending on the amount of lights included in the package. The system brings not only light, but can also power mobile charging. During a student project from TU Delft's industrial design students, a new design was outlined and also a prototype was build.

3.2 Solar home systems

Solar home systems have the purpose to power a complete household with different appliances. Mainly these appliances are lighting and phone charging, but they can also supply a radio or TV or even a fridge. For the home systems looked at in this project, the systems are powered by a solar panel between 50 – 150 W peak. Only SolarNow is also providing energy levels up to 250 W peak, which then can also power a fridge and TV. Nevertheless, the most important appliances for customers in the developing world are lights and phone charging.

SolarNow designs off-grid systems, which vary from small systems for only lighting and phone charging to bigger system with appliances such as fridge and TV. SolarNow believes in DC systems and is therefore only selling DC appliances, which is reducing the power electronics, since a conversion form DC to AC is not needed.

M-Kopa is like SolarNow focusing on solar home systems on a slightly bigger scale. The home systems include the solar module, battery and power electronics and different appliances, such as a radio, light bulbs and phone charging. They will start selling bigger home systems with the opportunity to power a TV from mid 2016. In order to make the system available for low income households M-Kopa uses a pay as you go payment system, where customers pay a deposit and weekly amounts for the duration of one year for their system. In January 2016 the first 1000 customers were able to finish with their payment for the solar home system.

SolarWorks! started with designing a simple light, but within the next month they will also sell solar home systems. That will then consists or more light balls, which can be placed in different rooms. The setup for the solar home system in shown in figure 5. Instead of one portable light ball, the system is integrated and can power five lamps.

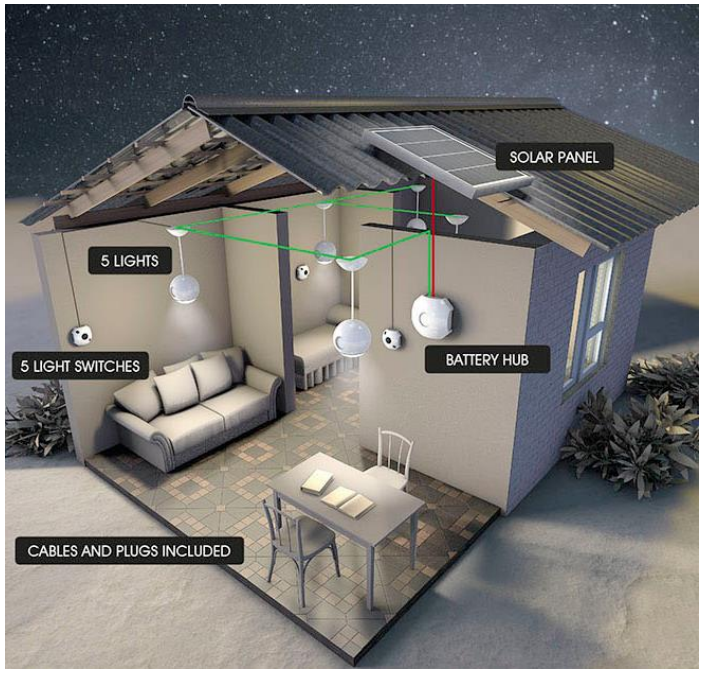
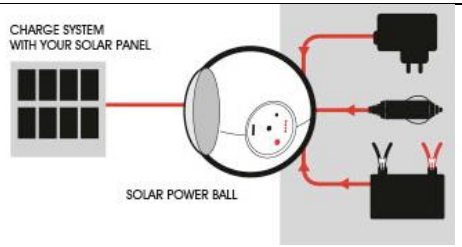


Figure 13 SolarWorks! home system configuration.

3.3 Community Solar solutions

Rural Sparks is a community based business model, which is selling energy instead of products. Within an area, customers can become a part of the business by being a local energy supplier selling energy to their fellow villagers.

During the **IEEE Sunblazer** project two different types of systems were developed. The Sunblazer 2 and the Sunblazer light. These two technologies differ in the specifications (details see Table below). Sunblazer II, the IEEE Smart Village flagship product, is a modular, easy-to-install PV solar-based community charging station. The PV panels are installed on a trailer and can then be connected to the village.

Simple products				
	SolarWorks!	Kamworks	Lemnis	WakaWaka
System composition				
Appliances	Portable light “ball”, phone charger	Portable light	Portable phone charger	Light, phone charger

Solar home systems			
	SolarNow	Onergy	M-Kopa
Systems composition			
Appliances	Radio, phone charger, lights, and for bigger systems fridge and TV (different sizes available)	Lights, phone charger	Radio, lights, phone charger

Solar solution for villages/communities			
	Rural Sparks	IEEE SunBlazer	
		SunBlazer 2	SunBlazer light
Systems composition			
Appliances	Lights, phone charger, radio, fan (2 system sizes available)	Lighting home system	Lighting home system

4. Project evaluation criteria

In order to get a better understanding and overview of all the projects considered in this report, the projects were split into three groups: simple projects, solar home systems, and solar systems for villages/communities. The tables on page 21 and 22 show an overview of the products and their applications. During the literature research, many criteria were considered with the goal of helping to understand and compare the different projects, their successes and failures. The focus was primarily on technical aspects. However also social aspects and the different business models used were investigated.

4.1 Technical Aspects

The technical aspects include the different components needed in solar products and solar home systems.

4.1.1 Battery type

The single major component, price wise, in all of these products is its battery. For the portable solutions two main criteria for choosing a battery are the size and weight.
By requiring the battery to be light and small, the available technologies reduces drastically. Compared to lead-acid the available battery technologies are also far more expensive. Therefore for the design of a portable solution for a target group of people in the developing world, the battery type is a very important criteria to look into.

Many battery technologies are available today but there major differences between these technologies. Table 2 shows the different simple products and solar home systems with their battery type and storage size.

Table 2 Portable solar products battery type and size overview

Portable solar products				
	SolarWorks!	Kamworks	Lemnis	WakaWaka
Storage Type	LiFePo4	2 x AA Ni-Cd	NiMH AA[9]	NiMh
Storage Size	6.6 Wh	2.7 Wh	5.3 Wh	800 mAh - 2.2 Ah

Solar home systems				
	SolarNow	Rural Sparks	Onergy	M-Kopa
Storage Type	Ni-Cd	LifePO4	LifePO4	
Storage Size	50 Wh	72 Wh	43 Wh – 86 Wh	8 Wh

[9] Conventional battery size

Depending on the purpose of the product, the decision for the type of storage changes. For example SolarWorks! focuses on the design of their product and places priority on the quality of several components and the total weight of the portable light. For that reason, the lightweight (high energy density) battery type (LiFePo) was chosen for their product. The same applies for the Solar Home system providers M-Kopa, Rural Sparks, Onergy, IEEE Sunblazer. Nevertheless for solar home systems, the need for a light and small battery is not as big as for a portable light i.e. the solar ball, since the battery can be placed inside the house and it does not need to be carried around. For the example of SolarWorks! the Solarball has a light and highly efficient battery in order to get a long lifetime (LiFePo4 lifecycle see table 2) and a light product.
The decicion for a battery type is always a compromise between costs, efficiency and lifetime and is always very much depending on the product and the product's targets.

4.1.2 Battery size

When choosing the capacity of the battery the geographical location where the product will be used has to be taken into account. In most of the areas that the products are used there is sunshine for about 9 hours every day during the whole year. When this is the case, the battery size can be much smaller than compared to a system where the battery needs to be able to cover several days without sunshine in order to prevent the system from failing.

4.1.3 Photovoltaic module

Portable solar products

As described in chapter 2.3.1 there are different PV technologies available on the market. The decision for one of the modules is, just like the battery always a compromise between all the factors, such as lifetime and costs. Table **3** shows the selected technologies for the portable solar products. Since the power is in a very small range the costs for the PV module can kept quite low at about 5 €.

Table 3 Solar module types and sizes portable solar products

	SolarWorks!	Kamworks	Lemnis	WakaWaka
PV module type	Chrystalline 1.8 Wp	C-Si 0.5 Wp	C-Si 1.6 W	Mono-crystalline 750 mW

Especially the information and the right treatment with solar panels is a very important factor when selling the products to the developing world, since the better the handling, the longer and more reliable the product is. I.e. in order to increase the lifetime of solar panels it is important to keep them clean and prevent them from physical damage, such as scratches caused by trees or bushes

blowing in the wind. Scratches in general are very harmful for the lifespan and efficiency of the module. Also a regular maintenance can increase the lifetime.

Bringing the product to the customer therefore always includes education about the electricity in general and especially also about photovoltaic technologies. Onergy and SolarNow! have local employees who are informing the new customers about the handling of the solar systems. During several field researches of the different project is was also possible to see, that many people in the developing world have a basic idea about solar products, but still need a more detailed explanation in servicing of the system/product.

4.1.4 Comparison of products

Figure **14** shows an overview of all the projects looked at. It can be seen that the portable solar products are all in roughly the same region of the graph. M-Kopa and Onergy do not differ very much in storage and panel size either. Since Rural Sparks is a village based solution it also needs far higher storage and solar panel sizes, to power the higher number of people in the village and more appliances. SolarNow is also in a higher region regarding storage and panel size. All three SunBlazer technologies have a much bigger (in the order of 100 times bigger) solar panel size and storage size. Therefore only the numbers are shown, but they are not added in the graph.

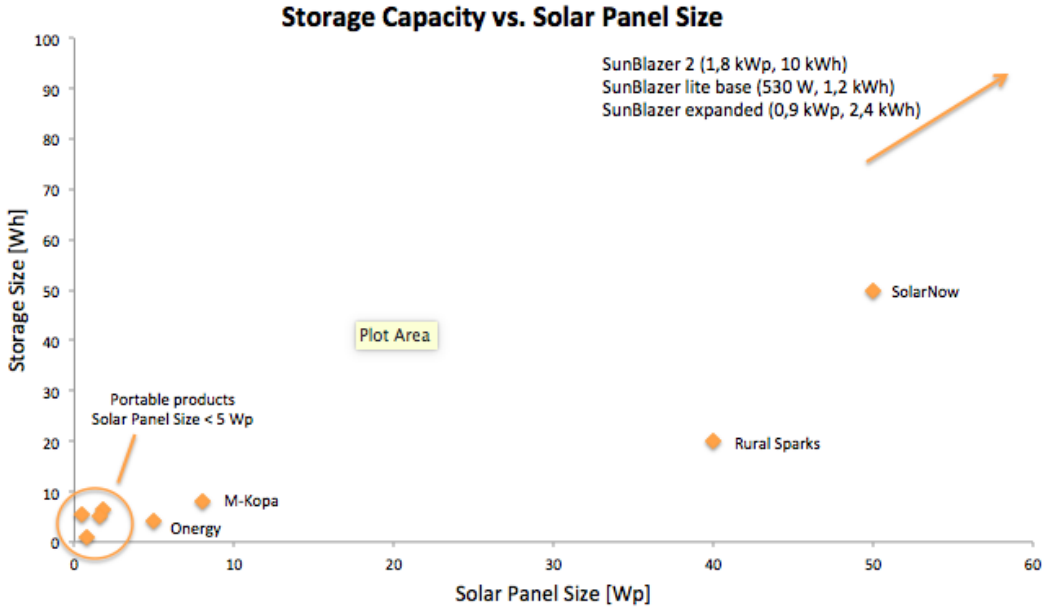


Figure 14 Storage Capacity vs. Solar Panel Size all products

4.1.5 Operation in DC

To avoid costs and make the solar home system less cost intensive SolarNow is offering their system with DC appliances only. Also their biggest system with TV and fridge, powers these appliances with DC. SolarNow for example believes, that the future for solar home systems used for developing countries lies in DC appliances. Therefore all their products are powered and used in DC.

4.1.6 E-waste

The E-waste was not considered in the projects but it is an important factor for solar based solutions. For future work and the further research into solar products a detailed view into the topic e-waste should be made and considered to find solutions that are sustainable and environmentally friendly solution.

4.2 Costs

In this section, the prices for all the products are investigated. Furthermore, for bigger solutions, the solar home systems and the village based solutions, the payment strategy is discussed.

4.2.1 Simple solar products

Table **4** shows the costs for the portable solar products. In order to make a better comparison, also the applications are shown in the table.

Table 4 Prices portable solar products

Portable solar products				
	SolarWorks!	Kamworks	Lemnis	WakaWaka
Price	~ $ 20	$ 15	~ $ 25	Donation
Application	Portable Light, phone charging	Portable light	Portable phone charger	Portable light, phone charger

For a further analysis of the portable solar products, a comparison regarding the costs per Wh (storage) and per Wp (solar panel) was done. Figure **15** shows the result shown in a graph. It can be seen, that the Kamworks, SolarWorks! and Lemnis products are in a pretty similar price range and only the WakaWaka product has a much higher overall price. Since the WakaWaka light and charging device is only sold in Europe and developed countries whereas it is donated in the developing world. The price depicted in the graph is from the European market and therefore is very high. Important Is to realise that for this price 2 products are physically sold: 1 to the buyer, and 1 is donated via an NGO in a developing country. The 45 degree line in the graph shows a trend line of the products.

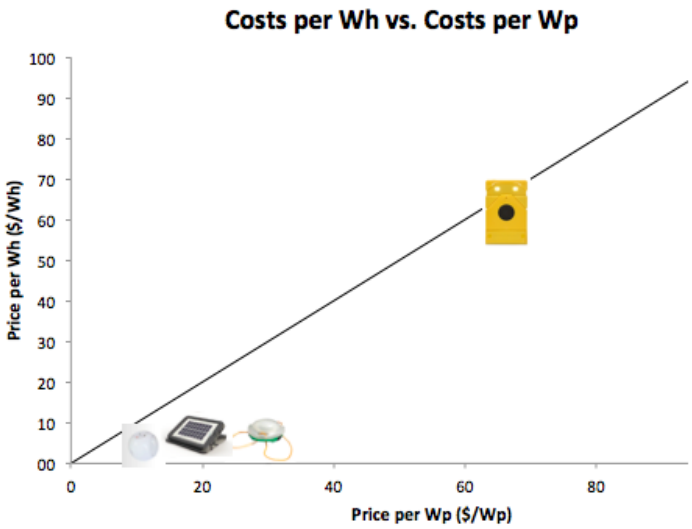


Figure 15 Product price comparisons with Wp and Wh

4.2.2 Solar home systems

M-Kopa and Onergy are already selling solar home systems in Africa. SolarWorks! is not yet selling the solar home system, therefore the price is not yet available.
M-Kopa has been selling solar home systems using a pay-as-you-go system since 2014 and is selling the product in Kenya, Uganda and Tanzania. The payment system consists of an initial deposit followed by 12 monthly down payments. After all payments have been made the system is officially payed for and the ownership is transferred.

Table **5** shows the costs for an M-Kopa solar home system, with an 8 Wp solar panel. The costs for the solar system are taken from the official M-Kopa website[10]. The table also shows the costs in euros. The change rate was taken in March 2016.

Table 5 M-kopa product pricing

	Kenya	Tanzania	Uganda
Deposit	3500 KES 31,11 €	690200 TZS 28,49 €	130000 UGS 34 €
Daily	50 KES 0,44 €	1000 TZS 0,41 €	1700 UGS 0,45 €
Total	4100 KES 191 €	57012 TZS 178,14 €	150400 UGS 198, 25 €

[10] m-kopa.com (last visited Feb 2016)

4.2.3 Community solar systems

Rural sparks and the IEEE Sunblazer are the two community based solar solutions. Rural Sparks is a business to business corporation. They sell their solar system to an entrepreneur in the village and then the people from the village can charge their products (phones) and buy energy for a certain amout (the specific costs were not be found)[11].

People using the Rural Sparks system are therefore paying for a service (the energy) and not for a product. The customers are therefore not "owning" the solar solution in the same sense as is with the portable solar products or the solar home systems.

Onergy is also using a pay-as-you-go system to sell the products, were they have different sizes. Sizes means that the product can power more light or is able to charge more phones.

4.3 Business model

The business models vary especially for the portable solar products. Products like WakaWaka are also sold in Europe and with every sold product in Europe, one gets sponsored in the developing world. Whereas SolarWorks! sells their products directly to the customer or even to NGOs, which can bring the product to the people in rural areas.

WakaWaka as well as SolarWorks! are already on the market and successful businesses, whereas SolarWorks! is only focusing on the developing world, WakaWaka is bringing their products to customers in both developed and developing countries with the difference, that in the developed world the products are sold via an online shop and the products for the developing world are sponsored by every product sold in Europe.

4.4 Social Aspects

Social aspects play a very important role for achieving success in the developing world. The benefits of having access to electricity or an electrical device considered socially can be:

- Further entrepreneurship
- Creation of jobs/Working extra hours
- Electrification
- Education
- Healthcare

[11] rural-sparks product brochure: http://static1.squarespace.com/static/5571fa8ae4b0601c9cc7bd6e/t/55735a6ee4b03b8cbd3ea2f5/1433623150912/RuralSpark_ProductBrochure.pdf

4.4.1 Further entrepreneurship

Further entrepreneurship can be seen with different projects, but Rural Sparks has the highest entrepreneurship potential, since people can actually make a business out of the electrification by selling the energy to other village members.

Also the portable solar products can have a social entrepreneurial impact in the form of a retail branch (shop owners and people who are retailing the products).

In general an important aspect is, that when the projects turn into an actual company they can create and generate new jobs in the developing world. This in turn has a social spin off as it leads to a better education for the future employees, as they have to know more about the technology, sales, etc.

4.4.2 Creation of jobs

The creation of jobs can be seen in different ways. On the one-hand companies that grow in developing countries directly create new jobs by employing locally. They therefore have the potential to create good jobs for the local communities. on the other hand there is the indirect creation of jobs. This occurs as new possibilities are created through the existence of the newly introduced product. For example with electrification it becomes possible to work at night or differently (non-human powered). Families can therefore for the first time work after sunset and are not dependent on kerosene. Field studies have shown that shops stay open longer (after dark) and that also students study longer (also when it is dark) due to the introduction of electric lighting increasing current and future spending potential. [7], [8], [9]

4.4.3 Electrification

The goal of all the projects in general is of course the electrification of the developing world and the improvement of lives in these regions of the word. Nevertheless it is just a beginning especially with the portable solar systems, since customers in general would like to have bigger systems, which can power more and bigger appliances such as a TV or a fridge.

4.4.4 Education

When it comes to the products and projects with solar systems a very important thing to consider is education of the users. Most people living without access to electricity and a very low income have never heard or seen a solar system. Therefore the education of the target customer group is very important for installing the systems and bringing the product to the market successfully. But education is not only needed for the electric technology, but also in the sense which benefits solar systems can give. Often people cannot fully understand or even imagine why they would need a solar powered light solution. It is therefore very important to point out all the benefits that can come with the solar product, such as health benefits when using light bulbs instead of kerosene lamps. A very important aspect and a common example when it comes to energy poverty are

the study hours of students. Usually the only light source available is the kerosene lamp, which especially for kids is a dangerous solution and it is also not a very efficient way of lighting. Also it can happen, that a family does not have enough money for the whole month and runs out of kerosene so that the family wont be able to light their house anymore at night.
Education is a very important factor in ending poverty. Therefore a safe and reliable solution for studying at night can give a big improvement for education and new chances for the young generations.

5. Implementation plan & Feedback

5.1 Implementation plan – how products are brought to the customer

All the projects looked at during the literature research are projects that have been carried out by students or companies from the developed world. The challenge in such a project is to bring the product to the developing (and very different) world, where the people have a completely different culture and lifestyle. For that reason, not only the technical setup and the design of a product is important, but also a proper understanding of the customer's pain and the problem that needs to be solved.

All of the projects included a design phase and also for most of the projects, the team went to the field to test the product and also to connect with the people they want to reach with their solution. The feedback from the customer about the prototype gives new ideas and insights to think of ways to improve the design.

Figure **16** shows one example of the framework of the fieldwork performed in the Lemnis project.

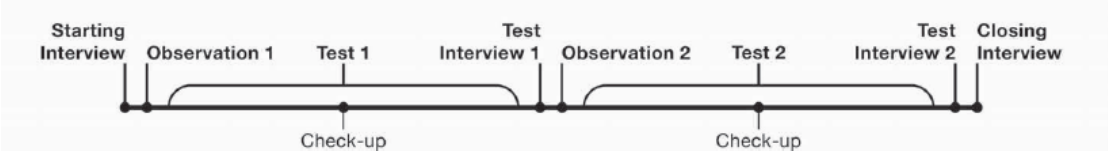


Figure 16 Example for a framework for field research.

Lemnis, Kamworks, SolarNow and SolarWorks! designed different prototypes and performed field research with these products. The target consumer group tested the different prototypes and after the evaluation of the different concepts, the final design was chosen. The customer feedback and also the communication with the end user turned out to be a very important aspect in the design process.

Many aspects regarding the design of a product for the developing world are things that are difficult to think of during the design process without any pre communication with the customer. Field research and the observation of the target user group, a discussion with the people and a final evaluation can therefore have a crucial impact on the product.

5.2 Customer Feedback

In this section some customer feedback from the several projects are picked and shown. The products were either tested in the field during the design phase or the feedback was given after the product was sold.

SolarNow talked to customers, who installed the solar home system. Three different kinds of customers were interviewed. Private home owners with the solar home system, a shop owner and a middle school institution.
Positive feedback regarding the system in private use are:

- The family is able to light the home in the evening
- The kids can study in the evening
- The family is more informed by the TV
- They feel that they have a healthier life, since they are not using kerosene lamps anymore

A shop owner was giving the following positive aspects:
- The system is very reliable
- The shop owner thinks the system is modular and he can expand it
- He is often showing off the product to others

The school gave the following feedback:
- The system is modular, so the school can expand it to more lights or TV's
- The system has a positive social impact

SolarWorks! During the design phase of the SolarWorks! light ball one fact, that could also be seen during the research of SolarNow, is that people are very careful with such electronic devices regarding their children. They are not fully trustful letting children touch or use the device. In the case of the light ball, the solution for SolarWorks! is to make it possible to hang the light ball from the ceiling. That solves not only the accessibility for children, but also the light ball cannot be damaged by personas stepping on it or by water or other exterior influences. Furthermore the light ball was designed in such a way, that it also gives most light in the hanging position.
Nevertheless half of the participants during the research indicated that they would use the light on the table instead of the ceiling. The appearance of the light on the table or cupboard shows their possessions to visitors. It is also possible to carry the light ball around and another very important function is the possibility to dim the light. That gives also the option the leave the light bulb on during the night, which is a very important aspect in the Malaysian culture.

Lemnis During the field research in the Lemnis project not only the feedback is an interesting fact, but also the locations where customers would use and take the portable solar panel to. Figure **17** shows the locations that were mainly used, where it was most common to use the prototype at home. Other locations were the location of work, the field and the church.

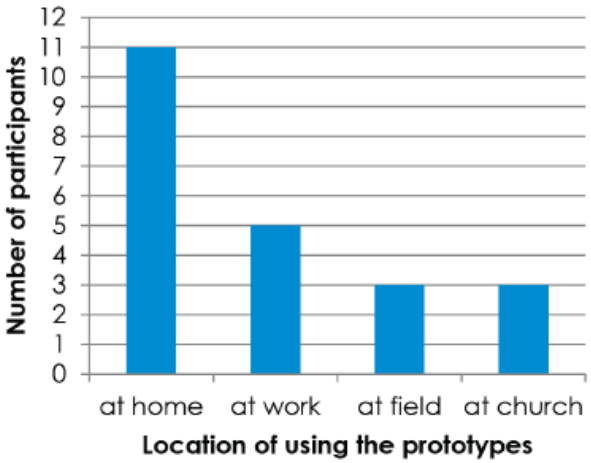


Figure 17 Location of using the prototypes of the field test participants.

From the field research the following conclusion points could be made:

- There is a need for such a product
- Customers are willing to pay for the product
- The participants in the field research had some basic knowledge about PV panels, i.e. that it needs to face the sun and can be adjusted during the day
- Some useful features, such as a strap to or a folding mechanism was not well understood and made the product more complicated, which confused the user

Kamworks was testing their prototype at eight households in the village Sre Amril, Cambodia. The main targets during that research was to find out if:

- The user understands the design and use of the solar panel and the light
- The designed manual was understood and made the intended use of the product clear

Two different design prototypes of the Moonlight were taken to Cambodia, where also a decision was made after the field research which design the final design should be. The two designs are shown in Figure **18**, the two prototypes differ in colour and one of them was fully working. During the research, the participants got the product handed out and were ask to use them.

Figure 18 The two Kamworks Moonlight prototypes in different colours

The Moonlight was designed to be carried around, not only holding it but also hanging it around the neck. Figure **19** shows the different ways that the device can be used.

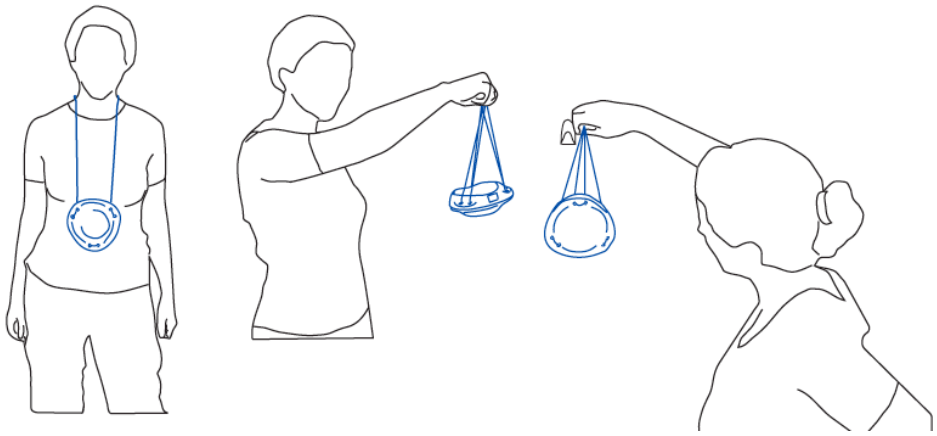


Figure 19 How to use the Moonlinght lamp

The following conclusions were made after the research

- After handing out the product the users were straight away using it as proposed, without any explanation
- The product solves the problem regarding unsafe and expensive light solutions
- The users were enthusiastic about the product and were willing to pay for it, even though it still represents financial effort
- They were aware of the benefits of the Moonlight compared to kerosene lamps
- They were critical about the plastic cover and the fact that the electrical components are not visible
- Frequently asked questions were regard to the lifetime of the light and the battery
- Participants were expected to be able to buy the product at specific shops, the “Koky” market and the “Preah Thamey” market
- The use of the switch was sometimes not understood properly. People did not dare to push it, since they have never seen such a switch before
- The feedback LED for indicating the charging process was very clear to the participants and they commented it as very nice and useful add-on
- The manual was understood well by the people, who were able to read. For participants, who were not able to read it, the pictures were not clear enough to understand the usage
- The usage of the solar panel was clear to most of the participants

6. Conclusions

Concluisions that can be drawn from this work can be split into the fields: Product Design and Implementation, solar lamps, finance and education.

6.1 Product design & implementation

One of the main aspects in order to make a project for the developing world is the complete implementation of the combination of all different aspects. That is not just the design and development of a prototype and the final product, but also the very close work with the target customer. Especially when the product is developed in developed countries often situation occur, where customers in the target countries are having a very different view on a product then the developer. Travelling to the target area, discussing ideas and the prototype with the customer is a highly important step, which can bring many news ideas for both the design and the functionality the product should have.

During the design phase it is a very important step to travel to the target countries and test prototypes with the target customers. The feedback from users can change the final design and can also point out what is understood by the customer and what is not useful to implement in the product, since some features are not understood and appreciated by the user. The feedback from a field research can have a great impact on the design and improve its implementation in the market.

6.2 Solar lamps

The access to electricity especially when focusing on light can improve and change peoples live in rural and developing areas remarkable. When comparing solar solutions with conventional kerosene lamps, a solar system can be much less cost effective in the long run, it is much safer and more environmental friendly. The main areas of the daily life's positively affected by solar solutions are:

- The possibility to work extra ours
- Studying at night for kids
- The business with solar products can create new jobs with regular income for people in developing counties

In community based solutions further entrepreneurship can be created giving new jobs.

6.3 Finance

Since the target group for the solar products looked at in this report are living in under very poor conditions with a very low and often also irregular income one of the main focuses to bring the product to the customers is financial. In the report different strategies can be seen, such as bringing the product to the customer with donations and not selling the product, but giving it for free (Waka Waka). Or to work with a pay as you go system in order to make the solar solution available. If the product is inexpensive such as the solar ball from SolarWorks! people are actually able to afford the product and are able to buy in in one go.

6.4 Education

Solar solutions for the electrification in rural areas can have a high impact on education. As seen in the field research, often people did not know much or rather nothing about solar power. Implementing simple products or solar based home systems can also give the opportunity for education in the area of electricity.

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