RESEARCH 2 | ONDERZOEK 2

Solar Energy in Sub-Saharan Africa

A solar cost-benefit analysis of Uganda

Research on behalf of UNICEF

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List of abbreviations

AC = Alternating Current
Ah = Ampere hours
Amperes = Watts/Volts
ARI= Acute Respiratory Infection
CFL = Compact Fluorescent Lamp

DC = Direct Current
DD= Digital Doorway
DMGs = Development Millennium Goals
GHGs = Greenhouse emissions
kVa= Kilo Volt ampere
Kw=Kilowatt
LED = Light Emitting Diodes
M&R = Maintenance and Replacement cost
NGO= Non- Governmental Organization
PV systems= Photovoltaic systems
Wh= Watt hours
Wp=Watt Peak
WHO = World Health Organization

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Generator in kilo Volt Ampere (kVA)	Max. output in kW
kVA 1	1
kVA 2	2
kVA 3,6	3,3
kVA 6	4,8
kVA 8	6,4
kVA 16	12,8

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Year	1991	1993	1995	1998	2000	2002	2004	2006	2008
Price	55	71	85	68	75	70	88	101	122

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	Initial cost	Maintenance cost
Pv modules	$6174.50(5000 euro) per kW peak	$61.75(50 euro) a year per kW peak
batteries	$247 (200 euro) per kW hour	$2.47(2 euro) per year per kW hour
converter	$617.45(500 euro) per kW	$6.18(5 euro) per year per kW

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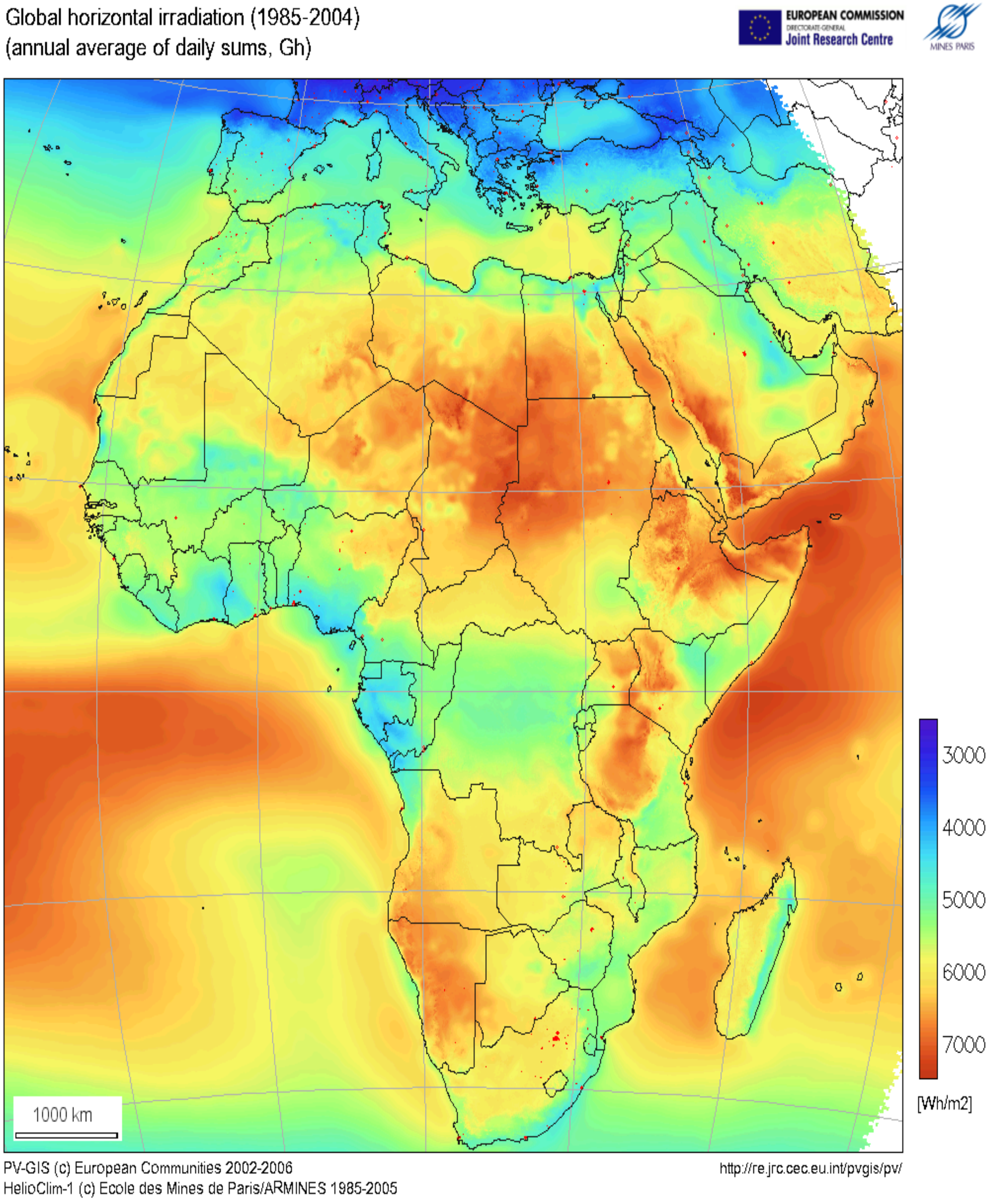

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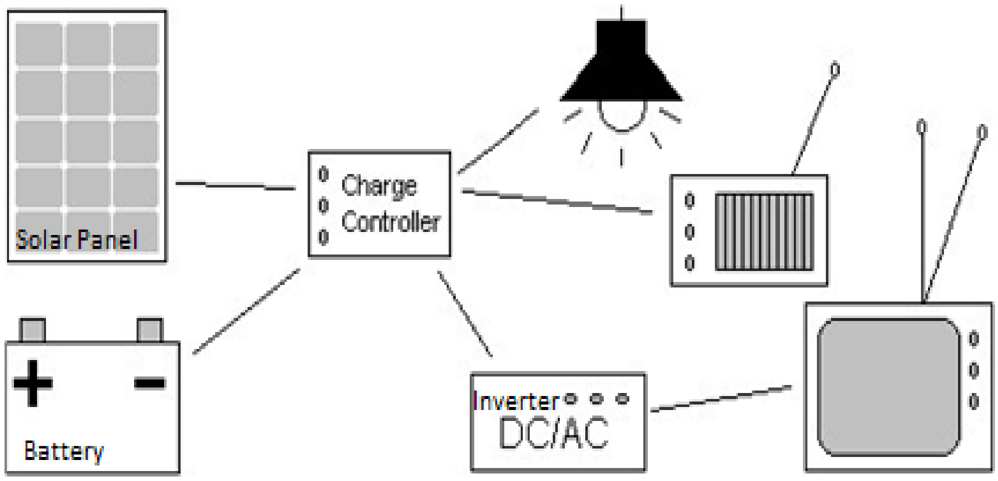

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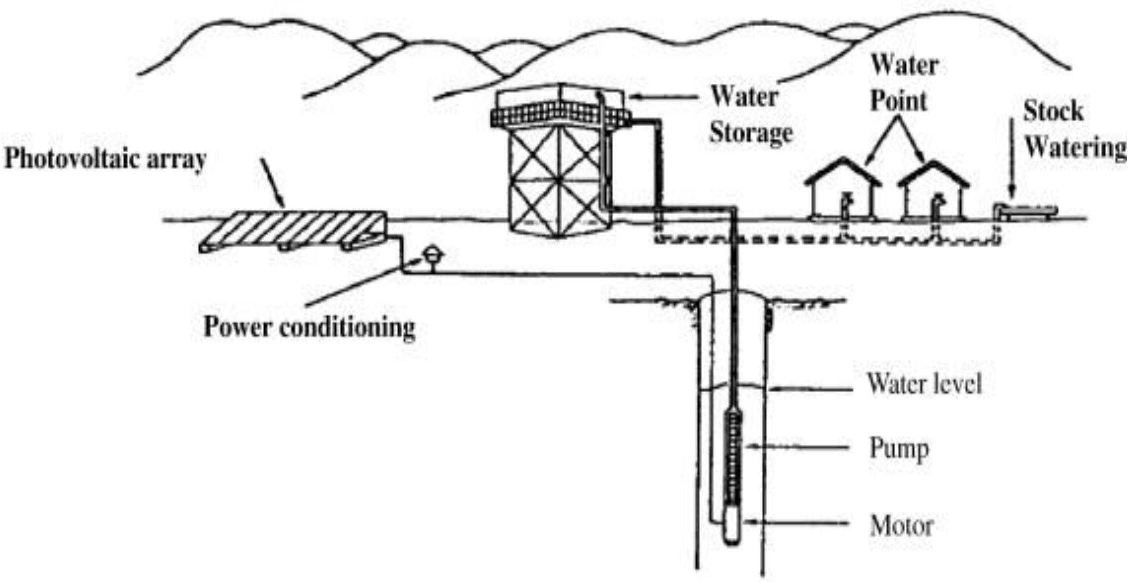

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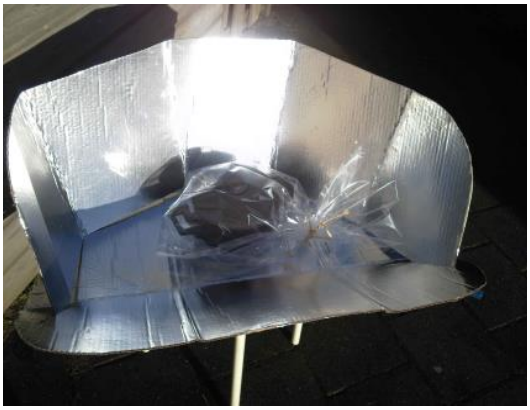

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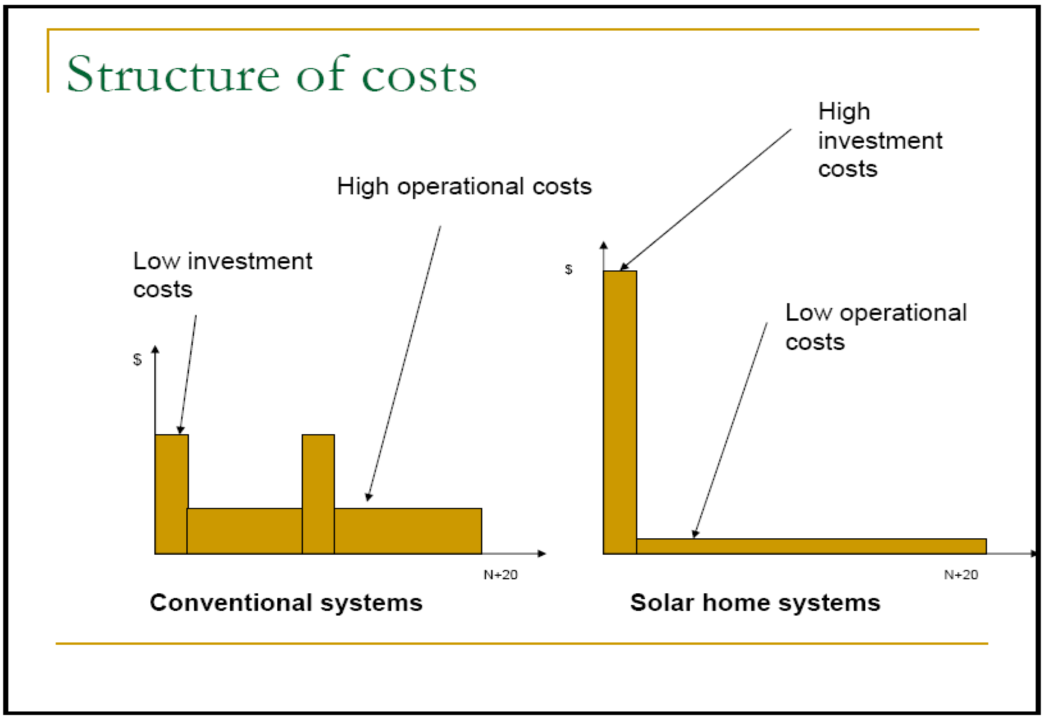

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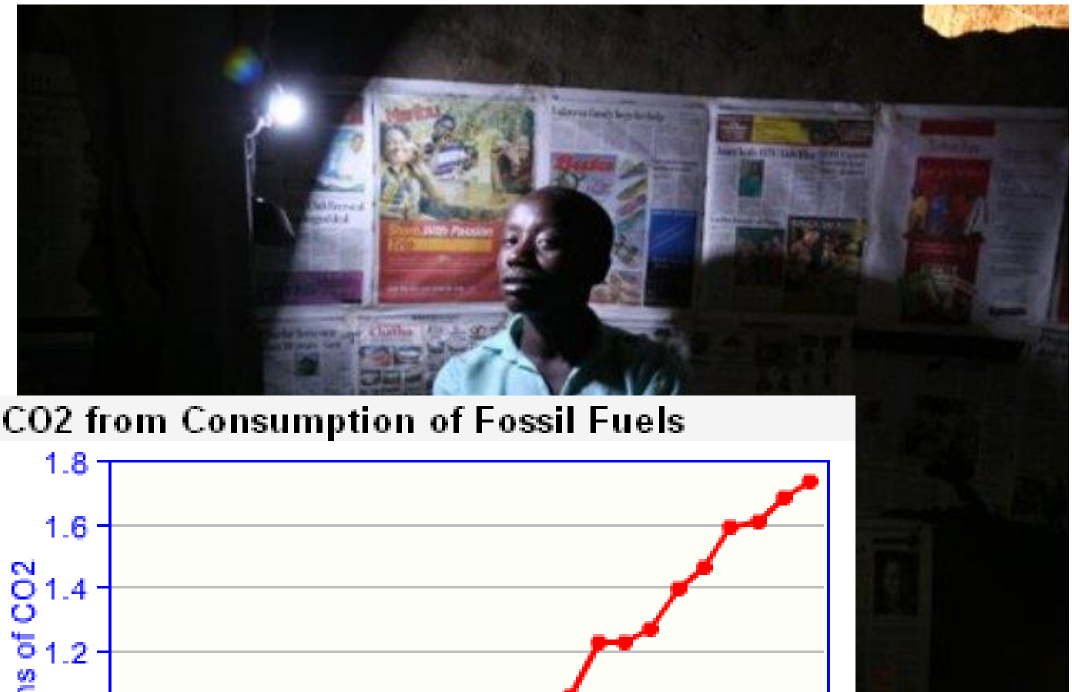

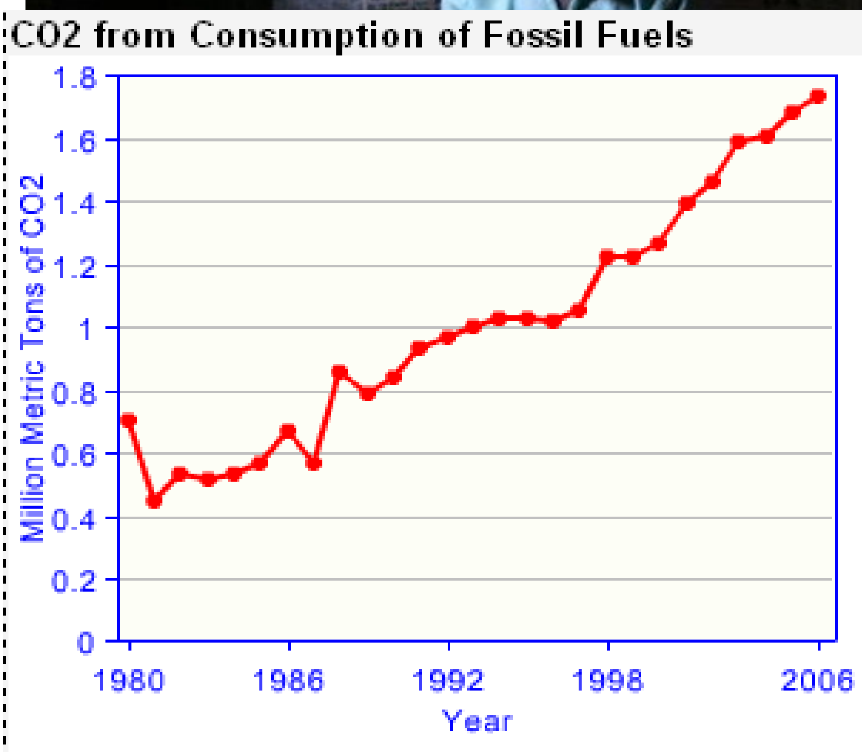

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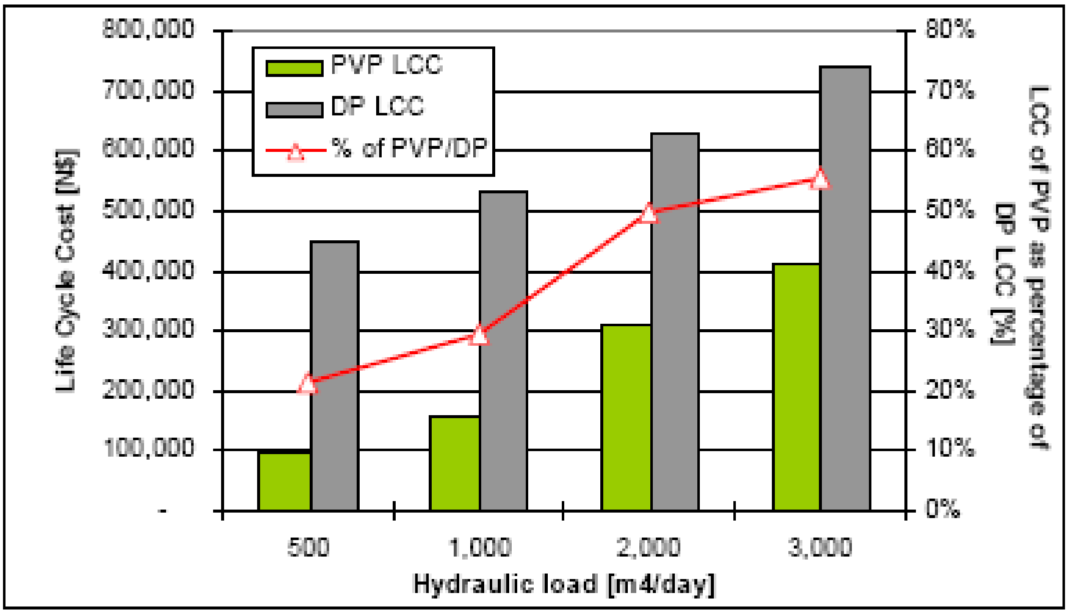

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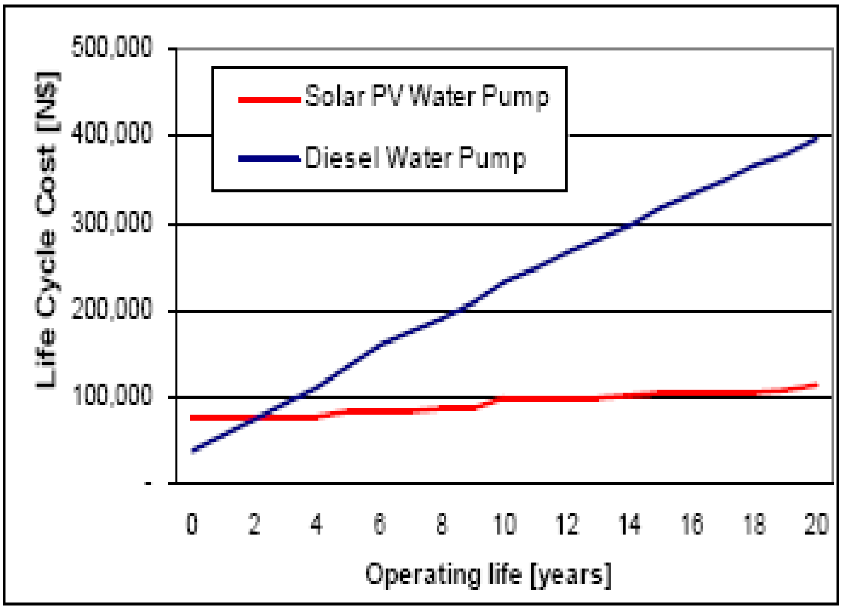

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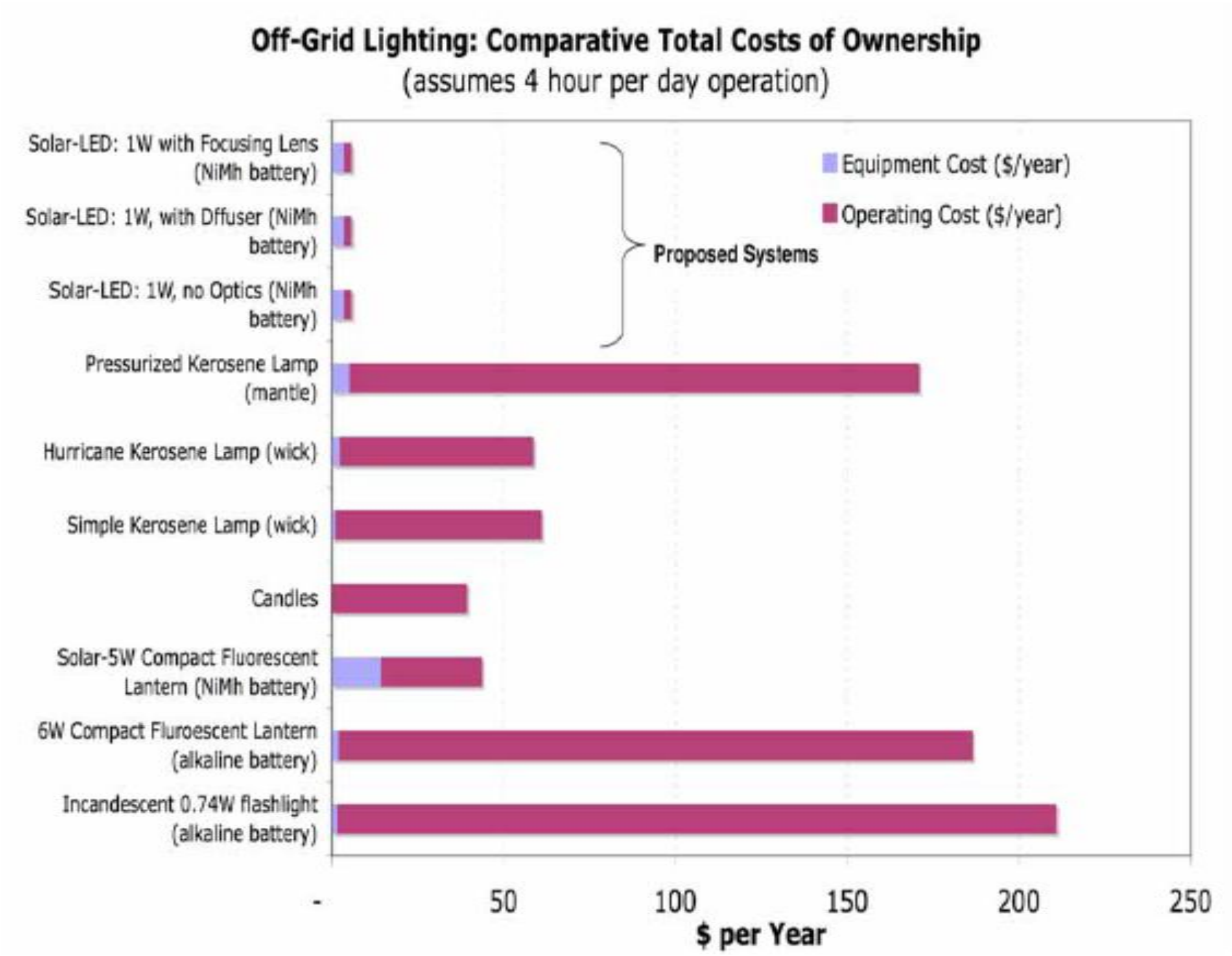

Introduction

"The sun, with all those planets revolving around it and dependent upon it, can still ripen a bunch of grapes as if it had nothing else in the universe to do."[3]
— Galileo Galilei.

Energy shortage is assumed to be of a major concern for the development of the Third World.[4] This may come not as surprise since in general each country that is regarded to be a developing country shows acute energy shortages. This means that only a small percentage of the population in developing countries enjoys grid access. In rural Sub-Saharan Africa 89 percent of the people live without electricity.[5] The main reason for this is the lack of state funds for expending the national grid to remote areas. Besides, government interests and these of its people often differ, which makes the construction of an electricity grid less likely to occur. Even if the people in remote areas would get access to the national grid, many will not be able to pay for electricity derived from it. Meanwhile, the sun is always providing warmth and strength that every living creature can freely enjoy.

Due to the difficulties with national grid access in the Third World, Non-Governmental Organizations (NGO's) and companies are considering other energy solutions. These can bring the benefits of electricity to the underprivileged peoples of the world, thereby providing a decisive stimulus to overall growth of a country. Certainly, there is good reason to assume that access to energy sources plays an essential role in the development of a country. Improving the level of healthcare in hospitals and the opportunity to study and work in parts of the day when there is insufficient daylight, are only a few examples of how electricity is interlinked with development. The UN Commission on Sustainable Development (CSD) states that "implementing the goal accepted by the international community to halve the proportion of people living on less than US$1 per day by

2015, access to affordable energy services is a prerequisite". In this way energy is directly or indirectly linked to all of the eight Millennium Development Goals (MDGs).

In this regard, solar technology takes in a prominent place. This is supported by the fact that NGO's are increasingly applying solar technology in their aid projects.[6] Part of its recent success originates in the fact that solar energy has become a viable and reliable option for rural electrification. Especially in Africa, where developing countries enjoy sunshine most time of the year, it has been considered to make solar power a common source of energy in the current situation of tremendous energy shortage. It is increasingly believed that solar energy, as being a renewable form of energy, is more reliable than other energy systems that work on traditional energy sources such as oil and gas.

However, the engagement of solar energy for development work is not without any downsides: costs and risks that are involved during and after implementation of the solar technology need to undergo a thorough analysis. Considering several factors that will be discussed later in this paper, we will show solar systems can provide electricity on a safe and clean basis. However, when these are not taken into account before implementation, there is a high probability that the project will result in a failure and will not contribute to development at all.

The objectives of this research are to provide guidelines for how projects involving solar energy can be implemented successfully and sustainably. In order to achieve this objective, this paper is divided into three deliverables that seek to address the following questions: Deliverable 1 will examine to what extent local populations in remote areas could profit from solar technology. As a next step, an overview of available solar technology for use in remote areas without grid-access will be given. The last section of deliverable 1 will analyze the difficult conditions that inhibit the implementation of solar energy. Deliverable 2 will shift attention to a cost-benefit analysis of solar energy in comparison with traditional energy sources. By taking financial, environmental and socio-economic aspects into consideration, it will be analyzed whether solar energy represents a more feasible solution than traditional energy sources such as diesel, kerosene and biomass. Based on these insights, the last deliverable will provide a policy recommendation for future projects concerning the implementation of solar technology in Sub-Saharan Africa.

By examining the advantages and disadvantages of solar technology in rural Africa, Uganda has been chosen in order to develop a framework that could suit many other countries of this continent. Despite a considerable reduction in the poverty headcount in the past decade, Uganda remains one of the poorest countries in the world. Access to electricity is at a low level, with a percentage of 19 percent countrywide and 3 percent in rural areas.[7]

Furthermore, this study will not include other renewable energy sources such as wind or bio fuel in its analysis since this would go beyond the scope of this work. Despite of this limitation, the reader should be informed that other renewable energy sources should also be considered and that, depending on social, environmental, economic and financial factors of the region in particular, it could provide another sustainable solution.

Deliverable 1|

The possibilities of solar technology in rural Uganda

1.1. Introduction

Being situated in the "solar belt", Uganda receives 2500 to 3200 hours of sunshine per year.[8]

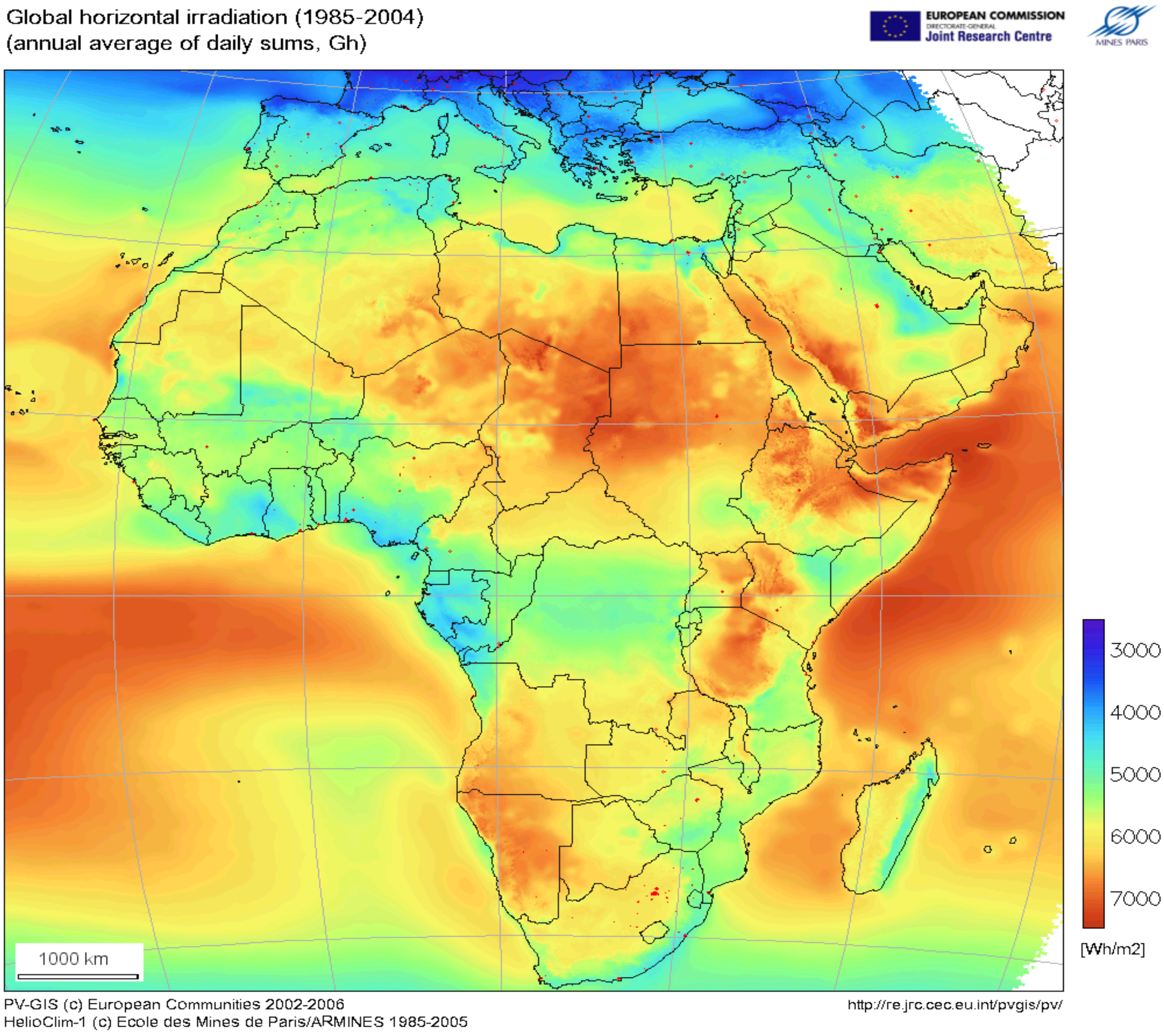

Figure 1: Wh/m²/day in Africa (source: http://www.geni.org/globalenergy/library/renewable-energy-resources/africa/Solar)

The illustration shows how these sun hours can be converted into an annual average of watt hours (Wh) per m² per day. When taking a look at Uganda's location on the map, we find a mean solar radiation of 5000 Wh/m² or 5 kWh/ m² per day. This unit of energy equals the radiation of a heater rated at 1000 watts (1 kilowatt), operating for one hour, or the use of an 11 watt light bulb consuming one kWh in (1000/ 11 ≈) 91 hours. It becomes obvious that the sun forms a reliable source of energy that should be exploited.

Photovoltaic (PV) systems gained favor in the global market after the energy crisis of the 1970's. But as the fossil fuel shortages were short-lived, the interest in PV rapidly declined. It is only in the last two decades that environmental concerns including global warming, caused partly by anthropologenic activities linked to use of fossil fuels, have led to increased attention towards renewable energy in general and to solar systems on the basis that these technologies are clean.[9] As the market for solar systems expanded accordingly, its technologies were further innovated, adding new possibilities to old techniques and inventing new and better devices. Simultaneously, penetration of technologies into developing countries emerged by support from various sources including multilateral agencies and private sector. As a result, today many solar technologies are developed for use in these countries and can be deployed taken with concern in all aspects of the development process, e.g. energy and communication, energy and health.

In rural Uganda, the lack of electricity hampers the development of households, education facilities and health centers which similarly have a tremendous impact on the lives of individuals and communities. This deliverable will focus on the possibilities that solar technology can provide for these problems. The main focus is on the following question: what are the available solar technologies that could be used in rural Uganda in education facilities, health centers and households and what are problematic conditions in the field concerning solar technology? To derive a clear answer, the following topics will be discussed: first of all, a broad overview of the needs in rural Uganda in the different sectors will be given. Secondly, the technology applicable in the specific sectors will be outlined and finally, the difficult conditions concerning implementation of solar technology in the field will be considered.

Please note that in this deliverable the financial aspects of solar energy will be completely left out, as they will extensively be discussed in deliverable two, where a cost-benefit analysis of solar energy versus traditional energy will be given.

1.2 Education facilities, health centers and households in rural Uganda

Below the current energy situation in education facilities, health centers and households in rural Uganda will be discussed. After outlining needs and problems caused by energy shortages or the use of other energy sources than solar, an overview will be given of possible solutions solar technology can provide.

Education Facilities

Education facilities in rural Uganda have two important needs: lighting and easy access to information. Due to the lack of both, an education gap between rural and urban Uganda has emerged that is hampering the development of remote areas. Because Uganda is situated on the equator it enjoys a fixed amount of 12 hours of light every day. The sun rises around 7 o'clock and descends at the same time in the evening. After approximately 7 pm people therefore have to depend on other lighting sources for the continuation of several activities. In most education facilities in rural Uganda, lighting after dark is either not available or of poor quality providing a disadvantage for all community members. Students are for example unable to continue their studies at night and lose hours of exam preparation. Furthermore, for many children, especially girls in rural areas, the lack of electricity translates into a missed opportunity to attend school as during the day they are overloaded with menial tasks such as fetching water and fuel.[10] The availability of lighting would facilitate these children to enjoy evening classes and similarly educate their parents after their 'work day' is over.

Another point of significance is the access to information. In a developed education facility, computers form a basic need as information technologies increase education opportunities and enable distant learning.[11] The Digital Doorway (DD) is an example which could, once installed, facilitate people to educate themselves in an easy and fast manner. In the 'solar tools' section the DD will be further elaborated on.

Health centers

Due to the absence of a structured energy network, relatively well equipped health centers in Uganda are mainly based in or near the capital Kampala. Health care in rural areas is therefore of low quality as these hospitals lack equipment such as refrigerators that can store medicine and have no proper lighting options during the night and/or partly during the day. This results in the causing of many unnecessary deaths every year, as surgeries cannot be performed and women give birth in uncomfortable conditions. In Uganda, an estimate of between 6,500 – 13,500 women and girls die each year due to pregnancy related complications. Additionally, another 130,000 to 405,000 women and girls suffer from disabilities caused by complications during pregnancy and childbirth each year.[12]

The improvement of rural health facilities could be supported by the implementation of PV systems, providing these buildings of electricity without the need to be connected to the grid. This could ensure a decline in child mortality, acute lethal situations and maternal deaths during and after delivery. Finally, solar lighting in remote locations helps maintaining qualified health staff, which would otherwise opt to work in grid-connected towns and cities.

Households

The main needs for a household in rural Uganda consists of access to water, lighting, communication facilities, and cooking. In dry areas the availability of consistent access to water, livestock watering and irrigation for agricultural activities is of high importance.[13] Today, people living in remote dry areas often have to walk many miles to fetch water and the hand pumps used here are unable to provide for large amounts. A solar-based water pump would contribute to the production of foods such as crops and meat (livestock watering). Moreover, by improving irrigation and the enlargement of producing crops, the capacity of the local farmers will increase which will contribute to their income.

These days, households in rural Uganda mostly depend on energy sources as kerosene, candles, biomass, and other non-electric sources for their lighting needs. These fuel-based lighting devices produce poor quality light at very low efficiencies. Solar-based lighting could provide for better lighting of households in rural off-grid areas for both indoor and outdoor purposes. A study by the foundation of lighting Africa in five African countries found that the main indoor nighttime activities that are significantly hindered by poor lighting are reading, doing homework and preparing food. Going to the toilet, tending to livestock and visiting are the main outdoor night-time activities that are significantly hindered by the lack of lighting. The main problems these households encounter without access to qualitative lightning, is the insecurity to go outside, the inability to do homework and the postponing of tasks to the day time.[14]

Another concern is the availability of communication technologies in rural households. The use of cell phones is an important form of communication in off-grid areas. Their significance has been shown in a research carried out by Gamos Ltd., a company working with social factors that accompany development, on characteristics of the use of telephones amongst rural and low income communities in three African countries - Botswana, Ghana and Uganda. This study indicates the increasing importance of cell phones in developing countries such as Uganda.[15] The key reason for this can be found in the possibilities a cellular provides. They can primarily be used to make long-distance rural-to-urban calls, which could for example allow farmers to inform themselves on the market price of their crops. Before, middlemen could name any price and local farmers were dependent on this given price. By providing local farmers and stake holders with communication technology, regulation of local trade will improve and farmers have a better chance of developing themselves and their farm(s)/company. Mobile telephones could also provide for long-distance communication among extended families or be of importance to certain types of rural or small town businesses. Many shopkeepers, auto mechanics, electricians, veterinarians, and other similar professions are dependent on mobile telephones to place orders, make business deals, or to keep in contact with their clients.[16]

Finally, households in rural Uganda make daily use of wood for cooking, which has several downsides. The acute respiratory infection (ARI), caused by inhaling the smoke of indoor cooking fires, is one of the five major causes of childhood mortality.[17] ARIs lead worldwide to over two million deaths every year. Women and children are especially affected, since they are most around the cooking fires.[18]

Furthermore, households could save time which could be used for other activities than gathering wood, hereby increasing household efficiency. Lastly, only partially substituting fire by solar energy will make a significant contribution to the improvement of the natural habitat of Uganda for the high deforestation that is going on in the country. The impact of traditional energy sources on the environment of Uganda will be further elaborated on in deliverable 2.

1.3 Solar PV systems

After having described the need for electricity in rural areas in Uganda or Sub-Saharan Africa as a whole, this part of the deliverable will cover a possible solar solution: the PV system.

By means of a physical phenomenon, called the photovoltaic (PV) effect, electricity can be generated from visible light. There are two basic kinds of systems which can store solar power: Grid-connected systems and solar PV-systems. Grid-connected systems feed the local main grid by converting sun light directly to electricity. Since rural Uganda hardly has access to a grid, this research will focus on the other type: the smaller solar PV systems or stand-alone systems, which can be used by households, schools, health centres and offices. The system size of a solar PV system can be expanded by increasing the battery bank and the number and/or size of the solar panels.

Usability

Since electricity plays a huge part in the development of rural Uganda, the usability of solar PV systems seems to be endless. The systems, depending on Watt peak (Wp) per size could, among others, be useful for providing electricity in villages in remote areas, medical facilities, communication systems etc. Wp is the output of a solar module in watts as measured under laboratory illumination conditions. In field conditions the output is always lower than the rated output.

Technology

The solar PV system consists of the following components: the solar panel(s), battery, charge controller and possibly an inverter. Below these components will be described further into detail.

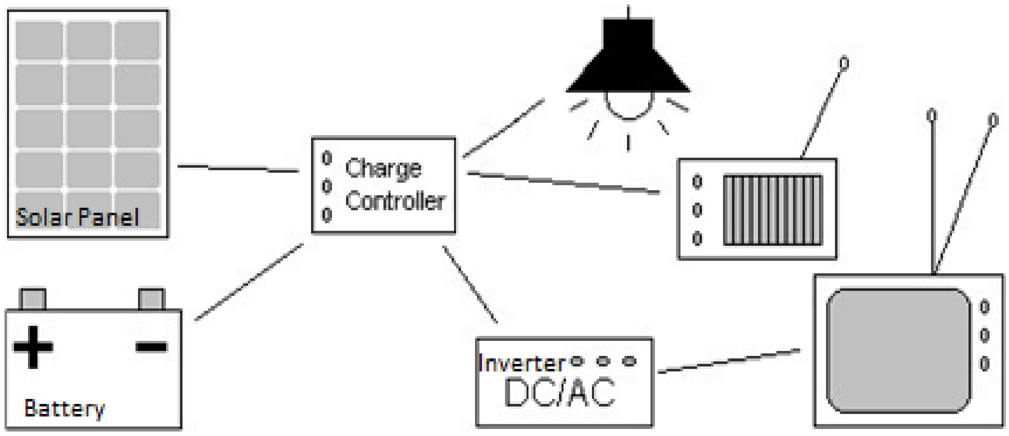

Figure 2: Solar PV system (Source: Sandgren 2001)

- *Solar panel*

According to the maximum power output (required amount of energy and maximum number of Watts a panel can produce for optimum external conditions), the number and/ or size of the panels can be rated. To determine the required solar array size in Wp, the total devices (in Watt) have to be multiplied by the amount of hours per day the devices have to operate. The result represents the required Watt hours (Wh). By dividing these watt hours by the usable full sun hours per day, the solar array size (in Wp) can be calculated. To give an example: given the fact that a place in Uganda has six usable sun hours per day, streetlights of 240 watt in total require a 200 Wp solar array in order to function for five hours. 240 watt multiplied by five is 1200 Wh. 1200 Wh divided by six sun hours is 200, which means that the streetlights require a 200 Wp solar array.

- *Charge controller*

Solar panels will not always collect exactly the same amount of energy. A battery in a solar PV system can be damaged if it is discharged or overcharged too often.

Produced energy needs to balance the amount consumed. Therefore a charge controller is needed to protect the PV system. A controller monitors the battery's state of charge, as there is a circuit to measure the battery voltage. When the battery is fully charged, the controller operates a switch to conduct power away from the battery. Only some very small solar panels function without a controller.

- *Battery*

Since there is a need to store energy produced by a panel, PV systems require at least one battery. The capacity of a battery is measured in Ampere-hours (Ah). An Ah is a unit of electrical charge. For example, a current source that delivers one Ah can deliver one ampere for an hour or two amperes for half an hour.[19] Like solar panels, batteries can be connected to increase Ah. The size of the battery bank depends on the storage capacity required, the minimum temperature at which the battery will be used and the maximum (dis)charge rate. The most common device used as storage is a rechargeable lead-acid battery. Their initial cost is relatively low and they are available nearly everywhere in the world. The suitability for use with solar cells is determined by the cycle life, the number of times a battery can be discharged. Many different types of batteries exist:

- *Solar batteries* are especially designed for PV-applications and can be cycled. From these batteries a lifetime of around ten years can be expected. The disadvantage is that they are expensive (starting prices $100) compared to conventional batteries and therefore very difficult to obtain in developing countries.
- *Traction batteries* are used to power electric vehicles. These batteries are ideal for solar power applications, if the necessary maintenance is conducted. The main disadvantage of this battery is its high cost.
- *Sealed batteries* are most suitable where a PV system needs to operate for long periods without maintenance. They have the advantage that they are spill-proof. However, they too are relatively expensive, require more charging control, and can have a shorter lifespan at high temperatures.
- *Car batteries*, mainly used for starting up vehicles, are cheap to produce and purchase (starting prices $30). The durability of the battery is low (5-10 cycles) and therefore inappropriate for PV systems. Despite of their lower reliability, car batteries are used in many developing countries where cost is a more important consideration.

- *Stationary batteries* are generally designed for un-interruptible power supplies. In regular solar PV systems this kind of battery is not advisable, although exceptions exist and little maintenance is required.
- *Leisure batteries* are usually the cheapest type of deep-cycle batteries. They are most suitable for smaller devices which are not daily used, as their cycle life is limited to a few hundred cycles. [20]

Within the PV system, the battery is the device that often causes the most trouble.[21]

- *Inverter*

Although the solar system provides a reliable substitute for the commonly used diesel generator, one has to keep in mind that not all original devices can be directly connected to the system. Solar panels produce direct current (DC) which is stored in batteries. Most kinds of load such as computers, televisions and lighting (except for 12 Volt lights) require alternating current (AC) in order to function. The inverter is the device that can convert battery-stored DC to the standard power AC. When products are designed for low voltage DC, they run on significantly less power.

Since access to fuel and funds to purchase the fuel can be a serious constraint, the introduction of solar power offers great possibilities. However, in case a diesel generator is replaced by a solar system, it might be advisable to change the original devices into products designed for low voltage DC. In health centres the purchase of new refrigeration can even be a requisite when installing a solar system. Kerosene or gas-powered absorption fridges are most commonly used in developing countries, and unfortunately, these fridges are often not suitable for solar systems. This in comparison to other devices that (with an inverter) can be directly connected to the solar system. Furthermore new solar refrigeration solutions have been developed which do not rely on the battery of a solar system, but can operate independently.[22]

1.4 PV water pumping systems

As opposed to a PV system, the solar panel in a solar water pumping system allocates the generated power “directly” to provide energy for a water pump. Thus, it has fewer components than the PV system since a battery, a charge controller or an inverter is not necessarily needed. The following of this deliverable will illustrate the usability and the functioning of this system.

Usability

One of the advantages of the PV water pump system lies in the fact that it enables access to water in remote and dry areas. Water supply is relatively stable since the pumps usually require little maintenance. A checkup is required only every three to five years. Secure water supply has a positive influence on rural development by its contribution to food security and the production capacity of local farmers. Apart from that, the availability and good quality of water is of great importance for health care. An example of the benefits of a PV water pumping system is illustrated in the field study underneath.

Field Study PV pump

The following field study shows how solar generated water pumps are contributing to the improvement of rural health centers and the community of the Rakai district in Uganda:

“Youth volunteers from the United States traveled to rural areas of East Africa to work with Solar Light for Africa, a faith-based nongovernmental organization, in providing power to clinics, orphanages, schools and churches. With USAID assistance, the organization electrified the Kakuuto Hospital in Uganda’s Rakai District using solar energy, which has improved the health of patients and enabled staff to treat them more effectively. Solar-generated water pumps, two miles of piping and two water storage tanks were also installed, bringing the hospital and greater community fresh water from a natural spring. Spigots were strategically placed along the route that allow nearby villages to access the water’’.

Source: http://www.hoise.com/vmw/05/articles/vmw/LV-VM-11-05-1.html.

Technology

A typical solar powered pumping system consists of a solar panel array that powers an electric motor, which in turn powers a bore or surface pump that pumps up the water (see figure 2 for the several components). These systems can include a battery bank to supply energy when sunlight is not available by storing unused electrical energy. However, the inclusion of a battery in the system has disadvantages. Firstly, batteries are expensive, thereby requiring high initial investment for the whole system. Secondly, while a qualitatively good solar panel has a life-expectancy of approximately 25 years, a battery commonly needs replacement after four to five years. Thirdly, a battery makes the system more

complicated, requiring specialized workers and some maintenance for good performance and operation.
Instead of using batteries, water can be stored in a reservoir. If there is no battery in the system, water is pumped as long as the sun powers the solar panel, which in turn operates the pump. Consequently, water is supplied even when there is no current need. However, a water tank, which is simple and cheap, can store the water.[23] Furthermore, without a battery there is less stress on the pump, since it will not have to operate during the night.[24]

Moreover, depending on the power the water pump needs, an inverter might be required to convert DC to the standard power AC. Apart from that, there are specific pumps on the market that are designed for PV systems. Usually, these pumps have a higher efficiency, which allows for a smaller size of the solar array, thereby decreasing the costs of the whole system.[25] This might make an initial investment more likely.

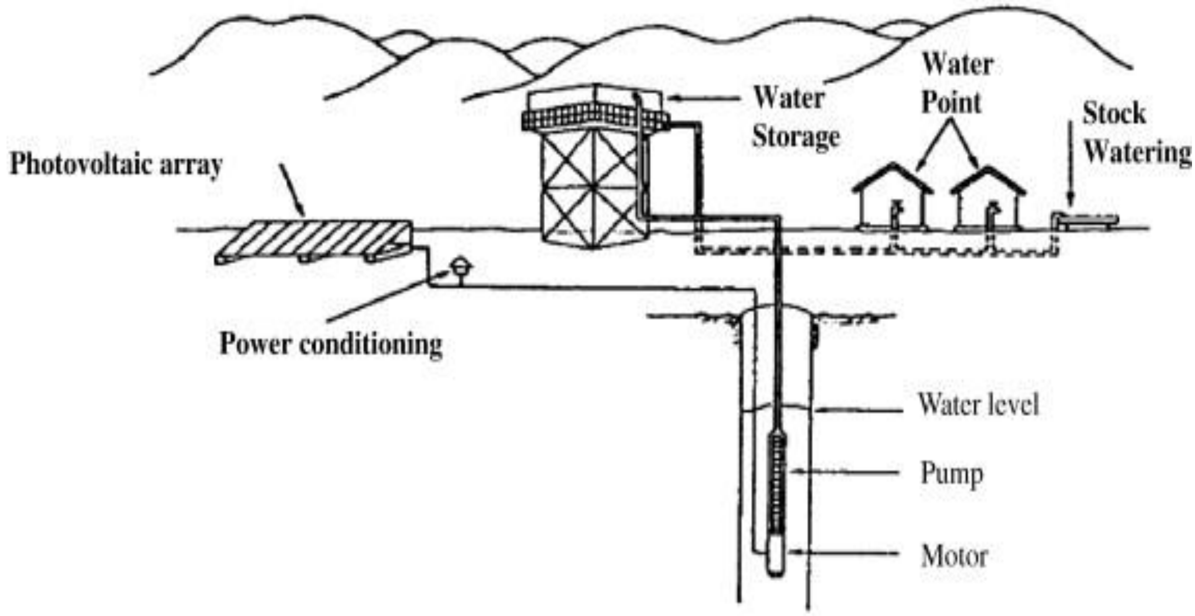

Figure 3: Waterpump system (Source: J.S. Ramos)

1.5 Solar Tools

Besides the Solar PV system which can be connected to several applications, other specific technology has been developed to advance the use of solar energy. These solar devices have solar cells included in their design and do not need the investment of a separate solar panel. This section will provide an overview of available 'Solar Tools' suitable for use in rural Uganda. Devices in the following areas will be considered:

- Lighting
- Communication and Information technology
- Cooking

1.5.1. Lighting

In solar lighting devices, solar cells convert sunlight into electricity that charges a battery, which then produces light for use after daylight. The most common lighting source used in such solar devices is the compact fluorescent lamp (CFL), though recently more efficient light emitting diodes (LEDs) have become more widespread.[26] Both technologies promise portable lighting and higher quality lighting and can be used in the form of lanterns, torches, task lights and area lights.[27]

Overview of available solar-based lighting tools: products, advantages and concerns.

- Torch

Products: LED Torch, Super BOGO
Advantages: Portable, Durable, User friendly, Bright light.
Concerns: Unidirectional illumination, Unit prone to theft during to outdoor charging

- Lantern

Products: Solar Lantern, Indigo, Solar CFL, Solar LED
Advantages: Bright light, portable, takes up little space
Concerns: Tiresome charging, not perceived as durable.

- Task Light

Products: Firefly, Replaceable Battery LED, Solar CFL
Advantages: Portable, Economical, Bright Light, Multifunction (as torch or lantern)
Concerns: Heavy, fragile, panel prone to theft during outdoor charging

- Area light

Products: AC Power Pack, Solar Power Pack, Flood lights, Spot Lights

Advantages: Bright light, Economical
Concerns: Heavy, panel prone to theft during outdoor charging.[28]

All devices can be charged by solar power and have a rechargeable battery. The designs are easy to use and are flexible. They are able to generate light up to 12 hours, taking into account that the hours of light is based on solar charging in full sunlight at 25 degrees Celsius.[29] However, the light intensity determines the hours of light that a system is able to produce. With high intensity, a system can generate light for approximately 4 hours; on low intensity it can produce light up to 12 hours or more, depending on the brand.[30] Below an example is shown of one of the newest inventions on portable solar lamps.

Solar lamps can provide a significant impact on the lives of people concerning health, education and income. In both schools and households. The lamps provide a sustainable source which advances the learning process of children. Especially at night people will be able to continue their activities indoor and are therefore more likely to develop themselves faster which eventually will contribute to their income and personal level of welfare.

Figure 4: D.Light $10 Kerosene Killer
(source: www.dlightdesign.com)

1.5.2 Communication and Information technology

- <u>Mobile Charger</u>

A solar mobile charger consists of a solar panel and a converter that enables the plugging in of chargers for all sorts of mobile phone brands. The size depends on consumption and purpose. For individual use, portable chargers have been developed. Communities can make use of a small PV-panel placed on top of a community building connected to a converter inside.

Figure 5: Nova S201

(source: www.dlightdesign.com)

Two devices in one: Nova S201

The Nova S01 is a LED-lamp that can also serve as an energy source for charging mobile phones. Mobile phones may be fully charged in as little as two hours.[31] The main benefit of this product contains the fact that now two important needs, mentioned before, can be fulfilled: The need of communication technology in off-grid areas, and secondly, the need for lighting. By using the Nova S201, the battery of the lamp and the cell phone are charged in the same amount of time. As a consequence, less material is needed.

- **The Digital Doorway**

The main aim of the Digital Doorway (DD) is giving rural areas the possibility to benefit from information technology. The philosophy of its sponsors is to "*lift rural communities out of poverty by giving them the tools and skills to do the job themselves'*".[32] The DD's aim consists of the installation of computer terminals at public places in rural communities, enabling people to educate themselves. This is possible since the terminals are easy to use and no prior knowledge is required. Users of these computers teach each other the necessary computer skills and thus vital knowledge becomes accessible in these regions. The terminals are constructed in such a manner that they are resistant to vandalism and destruction.

Figure 6: The DD and container DD in place (source: www.digitaldoorway.org)

It is important to mention that the DDs exist in multiple variations. They are available with one, three or four terminals and can be adapted for wheelchair use. The DD container can be located at places without grid power. The container is a self-contained unit with a solar panel installed on the roof, which charges a battery that accommodates three terminals with power. The DDs can be equipped with a satellite receiver and General Packet Radio Service that makes updating, real-time monitoring and user feedback possible. Also statistics from the system can be stored to determine whether it still operates and which applications are being used.

Due to the high costs, the DD is not considered to be a feasible solar tool yet. Though for the future they are likely to increase in their sufficiency for the DDs are still in their stage of development. For more information on the DDs and their progress in Third world countries we would like to refer to the sources that can be found in this chapter's bibliography.

1.5.3 Cooking

- Solar Cooking

Solar PV systems are not able to generate enough electricity for cooking. Here, another solar technology comes into play: the converting of sunlight to heat (solar thermal power). Although this technology has existed for a long time, it has only been recently that solar cookers for use in households are emerging on the solar market. The most common types of solar cookers suitable for households are box cookers and panel cookers. Hundreds — if not thousands — of variations on these basic types exist. Additionally, several large-scale solar cooking systems have been developed to meet the needs of institutions worldwide. Below, we will elaborate on the most used forms of a panel cooker: the Cookit and the solar box.

Cookits are made of cardboard and foil, shaped to reflect maximum sunlight and convert the light into thermal (heat) energy. A heat-resistant bag surrounds the pot, acting like a greenhouse by allowing sunlight to hit the pot and preventing heat from escaping.[33] The Solar box exists mainly of wood and contains an isolated box, covered with aluminum foil. The box has room for a 3 liter cooking pot and has the ability of cooking (almost) every kind of food. [34] Many solar cooker designs are portable and easy to build and use. They do not require any fuel and are therefore clean and save for the environment.

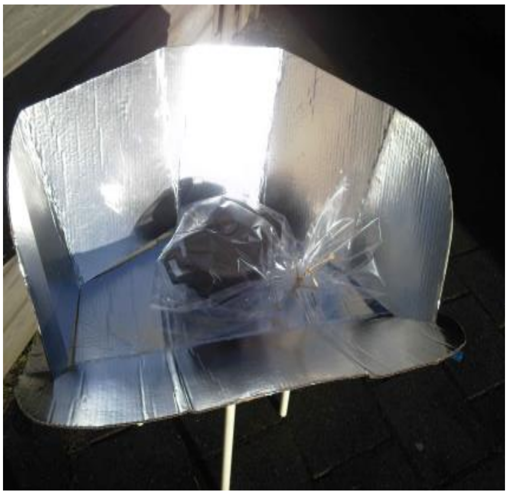

Figure 7: The Cookit

Figure 8: The solar box

In households the main energy source for cooking is wood and coal. After collecting sunshine for a few hours, by use of the Cookit meals can be prepares without the effort of collecting wood and coal. Moreover, the solar cooker makes it possible to cook food while preserving nutrients and avoids burning and drying out.[35] The downside of cooking on solar energy is its high dependence on the sun. Unfortunately, solar cookers cannot be used at night and are very difficult to use during the evening when the sun is not at its peak - which is usually when people go outside for cooking. In times of rain, cloudy days or fog, the cooker does not work and other energy sources have to be present to be able to cook. Further, the solar cooker is very vulnerable and its maintenance depends on several factors:[36]

- The solar cooker should not be mishandled
- The solar cooker should not be overloaded (>5kg)

- The solar cooker should never be left out in the rain or be allowed to get wet.
- The solar cooker should be cleaned once in a while; the reflector surface attracts dust, therefore it should be carefully wiped with a dry cloth.
- It should be carefully cleaned off with detergent and warm water in order to prevent the accumulation of dirt and grease.
- When the solar cooker is not in use, it should be placed outside of the sun or covered with a water proof cover.

1.6 Difficult conditions in the field

In the previous paragraphs the needs of education facilities, health centers and households were described and an overview of solar technologies to meet these needs has been given. Although it has been shown that solar technology has a lot to offer, there are several difficulties that have to be taken into consideration to make implementation successful and sustainable. Theft, corruption, absence of knowledge, and market constraints are factors that can have huge impact on the performance of solar technology. They will be discussed in this last section. Financial obstacles are left out on purpose as they will extensively be discussed in deliverable two.

Theft

In rural areas in Africa, most people can be considered poor. It is therefore not surprising that theft forms an obstacle when considering the implementation of solar technologies. The solar panels and its components are seen as high value items, for they consist of expensive and scarce materials which can provide for financial gain by selling them.[37] Also the energy that is created by the panels and components is scarce and therefore likely to be stolen so that the energy that is produced, can be resold. According to Uganda Village Project, a NGO that promotes sustainable development in rural communities in southeast Uganda, theft is a greater problem in urban Uganda than in rural Uganda due to the strong social cohesion in small villages and the severe punishment of theft.[38]

An example of the problems theft can cause is explained by a study of Short and Thompson, both teachers at the department of engineering in Durham. This study about water pumping installations elaborates on the security measures taken on six water pumping locations in South-Africa. The implemented installations needed security fencing, some with electrified fences and motion detectors, to protect them against theft. At the initial stadium of installation the panels were outside the dwelling, which made the facility an easy target for theft and vandalism. This resulted in many stolen solar modules. Although in a later stadium the panels were raised above the rooftops to avoid theft, the situation continued. The problems of theft were reduced after the panels had been installed upon the rooftops. Despite the fact that theft was reduced, the constant climbing to repair broken panels caused wear to the rooftop. [39]

A way to prevent these situations is suggested by Short and Thompson's research and also by Koen Dirven from the US-Dutch solar company Gira Solar. They propose that system ownership by a private individual or organization is a way to ensure safety of the panels and its components. As a result, villagers would have to pay for the water and would learn to appreciate the value of the panels. This idea is taken from Grameen Shakti (meaning Rural Power) – a subsidiary of Nobel peace laureate Professor Yunus's Grameen Bank – in Bangladesh. Here affordable solar home system have been developed and offered to the rural population through a soft credit facility.[40]

Another solution for the protection of the solar panel and its components could be ensured by an alarm which consists of a button, placed on the panel.[41] The alarm starts producing noise when a wire gets disconnected from the system.

Corruption

Since energy is scarce in rural Uganda, all devices that generate energy are seen as extremely useful and as a source of financial gain. In Uganda corruption is a common problem. The Worldwide Governance Indicators (WGI) of the World Bank in 2007 note that Uganda performed weakly in terms of corruption control. The WGI stress that corruption is widespread in public procurement, in tax administration, as well as in the police system and judicial institutions. In the Ugandan government there has been a tangible progress in establishing the required legal institutional framework to counter corruption. However, these efforts have only accomplished limited results and recent developments raise doubts about the sincerity of government efforts to effectively address corruption.[42]

As corruption is embedded in the Ugandan society, influential people could hoard the use of solar power for themselves through threats or other means of influence.[43] The selection of a headman serves as an example of how corruption can develop itself. Once a headman is in charge, he can determine that generated energy should be used for powering a television instead of pumping water for the villagers. In these situations it is likely that the villagers return to old water sources, instead of using the energy for the water pumping systems. Thus, in order to provide electricity by means of solar technology, the participation of the rural population and people who are familiar with the workings of the local system in solar projects, is important.[44] In deliverable three, possible solutions will be addressed.

Absence of knowledge

The absence of knowledge concerning solar technology poses a difficult condition in rural Uganda. The Uganda People Village project states that however people are poor and struggling with anything that requires expenditure of money, people seem to be open to innovative ideas and to anything that could bring electricity. They are eager to acquire access to electricity, which is especially evidenced by the fact that mobile phones are surprisingly common and in the fact that people run businesses for charging phones.[45]

Although the people in rural areas in Uganda are open to new means of generating electricity, for the successful implementation of solar technology, knowledge about solar technology is necessary. Technologies can be installed without proper maintenance, but will be unsuccessful for they will not be sustainable and therefore short-lived. Furthermore, people need to be informed about the supply that energy, generated by solar technologies, can provide. A common problem that occurs after implementation of solar technology is that consumers think they generate an unlimited energy supply. However, a solar PV system will only provide a limited quantity of power. This shows that a basic understanding of the capacity of the system is necessary. Only when people are able to accurately estimate the amount of energy available, the system will operate efficiently.[46]

Absence of knowledge could be solved if the group of people which receives PV systems is educated by the NGO's and specialists in how to use and maintain the PV devices. However, often there is no demand for PV systems in rural areas and service providers fail to introduce the systems accurately in rural communities.

Constraints on the market

According to a study on solar PV systems by Professor P. Balint, market constraints continue to limit the spread of PV technology into non-electrified areas of poor and middle-income countries. Markets on solar technology are constrained by several factors, such as poor families that cannot afford the initial capital investment or down payment. A lack of confidence and experience rules among marginalized consumers in the purchase of sustainable goods. Also a lack of service providers willing and able to sell, install, and maintain the systems in communities that are often difficult to work in because of their isolation and poverty in rural areas is one of the problems.[47] With a market-based approach, the collaboration of renewable technology and micro-credit can enable those without electricity to cross over the 'power line' of social inequality. Deliverable three will elaborate on this subject.

1.7 Conclusion

The energy shortage in Sub-Saharan Africa hampers the region's development. Especially people in rural areas, where there is no access to an electricity grid, can profit from the direct conversion of solar energy into electricity. This first deliverable has focused on the question what sort of solar technology is available for use in the field, while taking difficult conditions into account.

With Uganda as starting point, the first paragraph described the needs and possible benefits of solar energy for rural households, education facilities, and health centres. Concerning education facilities, two important needs can be distinguished: access to lighting and access to information. In rural health centers, main needs concern refrigerators to store vaccinations and lighting for deliveries and surgeries. Improved access to lighting would also contribute to the development of rural households as fuel-based lighting produces non-efficient poor quality light and is the cause of many health problems. These are not the only concerns which can be alleviated by solar technology. Solar-cooking systems can also contribute to health and household efficiency. Moreover, access to water for village supply, livestock watering and irrigation for agricultural activities are of main importance, since over seventy percent of Uganda's population is engaged in agriculture.

Apart from illustrating how rural populations can profit from solar technologies, an overview of available solar technology for use in households, health centers, and education facilities in rural Uganda is given. Without grid access, PV systems or stand-alone systems provide the basic technology for implementing solar energy in the rural part of Uganda. The size of these systems can be expanded by increasing the battery bank and the number and/or size of the solar panels. In this way the technology is not exclusively applicable to homes, but also useful for schools and health centres where more electricity is required.

For the purpose of increasing water access, water pump systems have been developed. As opposed to a PV system, the solar panel in a solar water pumping system allocates the generated power directly to provide energy for the water pump. No battery is needed. The water supply is relatively stable since the pumps usually require little maintenance without a battery.

Next to PV systems and PV water pumping systems, specific solar tools have been developed. The tools outlined in the fourth paragraph are stand-alone solar lighting systems: the Digital Doorway, the solar mobile charger, the CooKit and the solar box. Being made for specific purposes and independent use, the tools considered could also add value to existing power grids.

Although solar technology entails many possibilities, specific circumstances in rural areas can hinder the implementation of solar systems, PV water pumping systems and the solar tools. The conditions under which PV systems are installed are of great importance for successful and sustainable implementation. Theft, corruption and absence of knowledge concerning solar technology are important factors that have to be taken into account before implementing solar technologies. Further, constraints on markets to introduce PV systems in rural areas limit widespread development of solar technology.

After having discussed the manners in which solar technologies can contribute to the improvement of the life of rural populations in developing countries, the question of its costs – e.g. financial, socio-economic and environmental – compared to traditional energy sources needs to undergo a thorough analysis. Solar energy can only compete with traditional energy if its comparative advantages are substantial. Therefore, the next deliverable will be aimed at creating a cost-benefit analysis of solar energy versus traditional energy, making use of the insights won in this deliverable. In this way, it will be examined how and to what extent the implementation of solar power in rural Uganda can be advocated for.

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Deliverable 2|

A cost-benefit analysis of Solar energy versus Traditional energy

2.1 Introduction

The previous deliverable introduced rural Uganda as a model for the African continent regarding the implementation of solar energy. By taking rural off-grid households, health centers and schools in into consideration, it has been illustrated that solar energy possesses great potential to address the needs of the Ugandan people. In these areas however, solar power has to compete with the traditional energy sources used by the local people.

Uganda is endowed with different energy sources, which can be broadly classified into three groups: biomass, commercial (non-biomass) and alternative energy sources (on a very small scale). Biomass energy includes fuel wood and agricultural residues for domestic use. Commercial energy comprises electricity (hydro, geothermal) and petroleum products, while alternative sources include renewable energy such as biogas and solar energy.[48] Firewood is used by 81.6 percent of the households as cooking fuel, while 15.4 percent uses charcoal (in 2002 the Ugandan total annual energy consumption was estimated at 20 million tons of wood).[49] The use of commercial fuels such as liquefied petroleum, gas, and kerosene (paraffin) for cooking in rural areas is insignificant, whereas kerosene represents the major source of lighting for more than 90 percent in households in rural areas and for 58 percent in urban areas.[50]

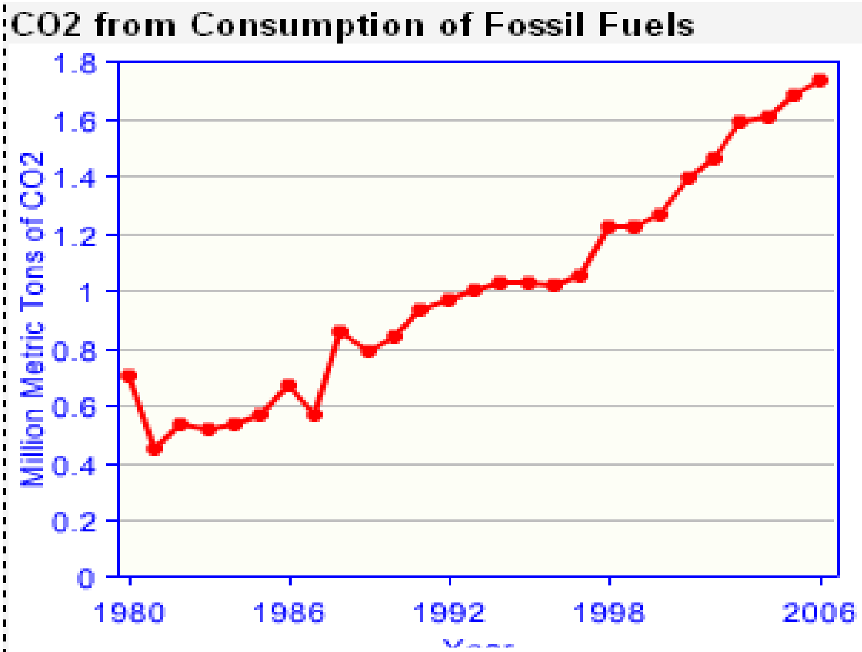
As the above shows, in contemporary households, schools and health centers in rural Uganda, the lack of electricity is insufficiently compensated by the use of firewood for cooking and kerosene for lighting. To provide community buildings with electricity there are several options that can be considered: connection to the grid network, a diesel generator, or sustainable power solutions. Grid connection is no feasible solution in rural areas, for a tremendous investment is needed. Projects that are needed in order to construct a sufficient power line will take up several years. Moreover, the price per kWh (454 Ugandan shillings) is generally too high for the local people to pay.[51] Besides, a connection to the electricity grid has shown to be an unpredictable source of energy. People are in doubt about the length of their power supply; as far as they know, their power supply could last between a few hours and a whole day. On the other hand, a diesel generator is a relative cheap source of energy and available in every medium sized business in Uganda. However, it has the disadvantage of requiring diesel to function which comes down to the fact that, depending on usage, diesel needs to be transported on a weekly basis. The transportation has been shown most inconvenient since the trucks cause pollution and the poorly developed roads counteract a prosperous transport. In order for the sustainable energy sources to compete with diesel generators, it has to be financially and socially more attractive than generators. Solar energy is of significant importance in this comparison, since it has a tremendous advantage over the generator in health centers and education facilities, which we will elaborate on later. Within households, several solar tools can replace the wood and kerosene used now, but similarly, these have to prove themselves more attractive.

This deliverable will provide for a cost-benefit analysis of solar power versus the mentioned traditional energy sources. The cost-benefit analysis will be performed on an environmental, a financial and a socio-economic level. In the first chapter, a general environmental cost-benefit analysis will be given. In the second chapter, comparisons between solar and diesel in general will be made in three analogous sections. In the third chapter, photovoltaic (PV) powered water pumps and diesel powered water pumps will be compared. In the fourth chapter, a comparison between solar tools versus the use of biomass (wood) and kerosene will be made.

The aim of this cost-benefit analysis is to create a full overview. Therefore, the advantages and disadvantages of solar energy and traditional sources will carefully be examined. An example method of calculation for both energy sources will be provided. In addition, the socio-economic aspects will be considered, for they are indispensable in explaining how different energy sources affect human lives and societies. The outcome will be helpful for those who consider the implementation of solar energy in rural areas in poor countries with no grid access.

2.2 Environmental aspects

The generation, transmission and use of energy affect all aspects of development. While social and economic effects in general can be considered positive, the impact on the environment differs highly when using different sources of energy. As many countries worldwide depend on fossil fuels to meet their energy needs, ecological and environmental problems are growing.[52] While the effects of climate change are growing more visible every day and fossil fuels are depleting rapidly, the belief has risen that provision of efficient and reliable energy services with minimum effect on the environment is crucial. At the same time, the insight has grown that the developing world does not necessarily have to follow the energy route of the industrialized nations, but can learn from their experience and mistakes by implementing other energy sources. Here lies an opportunity for these countries to make a switch to alternative energy sources before global warming becomes a life-threatening phenomenon.



Graph 1 ***Carbon Dioxide emissions in Uganda. Source: US Energy Information Administration.***

Solar energy is one of those so-called 'green' energy sources. With our focus on rural Uganda, the environmental impact of solar energy will be compared to the environmental impact of traditional sources of energy, also taking into account the future sustainability of both energy sources. Although African countries contribute only a small percentage of global greenhouse emissions (GHGs) in comparison with industrialized countries, projections indicate a much higher contribution in the future. In Uganda, fossil fuels are mostly used in the form of oil transport, petroleum products, such as kerosene, for cooking and lighting and diesel for electric power generation.[53] Graph 1 confirms the increased consumption of fossil fuels in Uganda since the 1980's apace with CO_2 that is released when the fuels are being combusted. Thus, as Uganda is becoming more dependent on a depleting energy source as fossil fuels, the environment is more and more affected. Both these factor make solar energy an increasingly unsustainable energy source for Uganda.

Besides the GHGs that are emitted through the consumption of fossil fuels, biomass comprises a giant source, as some ninety percent of the Ugandans rely on biomass as their primary source of energy. Biomass is generally considered to be a sustainable energy source. The Ugandan forests and woodlands do not only provide the people direct economic benefits such as energy, food, timber and non-timber products, but also indirect ecological benefits, such as water catchment, controlling erosion and moderation of local climate.[54] But as forests and woodlands are the main source of fuel for the majority of the households in Uganda, their use has logically risen apace with the high growth rate of the Ugandan population (3.3% annually between 2002 and 2008), leading to threats of deforestation and declining forest quality.[55] The decline in woodlands with an annual percentage of 2% between 1990 and 2005 has made the sustainability of the high dependence on wood questionable, in this way putting a danger upon the future livelihoods for many Ugandans.[56]

Other environmental problems in Uganda are constituted by the use of small dry-cell batteries for flashlights and radios. Most of these batteries are disposable lead-acid cells which are not recycled. The waste of lead-acid batteries can cause environmental issues and health concerns. Lead from disposed dry-cells leaches into the ground, contaminating the soil and water. Although solar systems also require batteries, they generally have a long lifespan and cause minor contamination when appropriately replaced. The provision of knowledge about the hazard of simply disposing the batteries can prevent future risks for the environment.

To anticipate on future problems for developing countries such as Uganda regarding fossil fuels, biomass and batteries, it is of high importance to start searching for alternative energy sources. Solar energy can solve environmental problems, as provide for a more sustainable and reliable energy source in the future of African countries. In an article published in Environmental Science and Technology in 2008, scholars investigated the life cycle of solar cells, from the mining of raw materials to the finished product, and concluded that overall all PV technologies generate far less air emissions than conventional fossil-fuel based electricity generation technologies.[57] The absence of any air emissions or waste products during their operation makes solar energy technologies a very clean alternative for the depleting natural resources the Ugandans rely on today.[58]

Concluding, the implementation of solar technologies in rural Uganda would provide obvious environmental advantages in comparison to the conventional energy sources. Also, they would contribute to the sustainable development of human activities.

2.3 Solar systems versus traditional system

A diesel generator generates electric energy and is used in places that have no connection to the power grid. Due to high usage of generators in rural Uganda, this form of traditional energy can be seen as a competitor of solar energy. Therefore, the cost-benefit analysis of solar energy versus traditional energy will start with an outline of their costs. Both systems will be divided into financial and socio-economic costs. First of all, the financial and socio-economic costs of the diesel generators will be illustrated. Secondly, the financial and socio-economic costs of the solar systems will be described. Subsequently, the outline of these costs will lead to a cost-benefit analysis of a diesel generator and a solar system. Finally, the use of the solar system in the rural area of the Mbarara region will be illustrated in a case scenario.

2.3.1 Diesel generator

<u>Financial costs</u>

Initial investment

A diesel generator produces electricity by using diesel as a fuel and has a build in battery charger. The financial costs involved with diesel generators are the initial investment, and after that, the operational costs which include the price of diesel per liter. The initial investment is the price of a diesel generator which depends on maximum output measured in Kw (Kilowatt). The output power of various generators is illustrated in the table.

Generator in kilo Volt Ampere (kVA)	Max. output in Kw
kVA 1	1
kVA 2	2
kVA 3,6	3,3
kVA 6	4,8
kVA 8	6,4
kVA 16	12,8

Table 1. The smaller 1 to 5 kilo Watt diesel generators are a feasible solution for small community centers in the rural areas, such as schools and medical centers. Their purchase price is approximately $1000. On domestic (second-hand) markets in sub-Saharan Africa, the prices are lower.

Figure 9: kVA 3,6 generator

This kVA 3,6 generator has dimensions of (LxWxH) 26.7 x 17.9 x 21.4 inch[59]*,*
weighs 143 lbs[60] *and costs $ 1000.*[61]

Operational costs

The main financial costs involved with diesel generators are in the first place the initial investment of the generator and in the second place the fuel costs. The initial investment is the price of a diesel generator which varies from 1000 dollars for the smallest generators up to 9,000 dollars for the largest generators mentioned in the foregoing table.

Diesel is an import product in Uganda and its price increased between the years 1991 to 2008, from 0.55$ cents per liter to 1.22$ per liter.[62] If this trend continues, the operational costs of a diesel generator are likely to increase in the future. In 2010 one liter diesel costs around $1.10 in Uganda.[63]

Year	1991	1993	1995	1998	2000	2002	2004	2006	2008
Price	55	71	85	68	75	70	88	101	122

Table 2, *Time Series of retail diesel prices in Uganda in US cent per liter*

Socio-economic costs

The socio-economic costs of diesel generators for the rural population of Uganda are dependent on the maintenance costs of the generator, the transportation costs of a generator to rural areas, noise, and pollution. The operational costs of a diesel generator are significant. Besides the rising fuel prices, a gas station is often situated miles away from the place where the generator is situated. The transport costs and pollution from trucks and the poor roads give rise to the high operational costs of a generator. Replacement of diesel is required every 100 hours or at least every three months if the generator is not used. If the generator is used constantly or in tropical climates, it will be necessary to change the diesel more often.[64] The use of synthetic oil will prolong the life of a generator. It can withstand high temperature and can work longer without losing its lubricating qualities.[65] Since the availability of the high quality synthetic oil is scarce and too expensive for the people in Uganda, the performance of a diesel generator would not be optimal. Time and effort will be lost by constantly traveling to the gas station for diesel in order to keep the generator running properly.

Further costs of a diesel generator are noise and pollution. However, it is difficult to provide costs calculations of noise and pollution of diesel generators. The inconvenience caused by noise and pollution is not similar for all types of diesel generators, but have to be taken into account.

<u>The diesel generator – total costs in steps</u>

Please note that the following steps are intended to help making a simplified cost-estimate and that the outcome does not constitute an exact representation of the total costs due to various factors that can increase or decrease the investment or operational costs.

<u>Investment costs</u>

Step one: *determine the total watt for the devices that need to be connected to the generator.*

Step two: *Determine which diesel generator is needed, by looking at its maximum output (kilowatt). The output should be slightly higher than the total watt needed, to be sure the generator will never fall short to supply all devices of electricity at the same time. The cost of diesel generation capacity is approximately 65 cents per watt installed.*[66]

<u>Operational costs</u>

Step 3: *The operational costs will mainly consist of the fuel costs. Today the diesel prices in Uganda are around the $1.03 per liter.*[67] *With the consumption rate of liters per hour at the specific output of the devices, an estimation of the main operational costs (the fuel costs) can be made.*

2.3.2 Solar system

After examination of the diesel generator, in this paragraph the costs of the solar PV system will be outlined. The price per Watt peak (Wp) is a measurement in which the costs can be displayed. Hence, a 300 Wp solar system costing $2400 in total (i.e. installation included) corresponds to a price of 2400/ 300 = $8/Wp. However, global average cost values which are generally used for calculations tend to hide the additional costs before technology gets to the consumer.[68] In developed countries these costs vary significantly from those in Third World countries. Due to the regional and cross-country disparities and sales taxes, the African local cost of a solar system is much higher than the purchase of a similar system in the United States. In April 2010, the average retail price was $4.23 per Watt peak in western countries. This price is exclusive of sales taxes, which, depending on the country, can make up to 20 percent of the prices.[69] In Uganda the price per Wp of an installed solar system is approximately $8-10.[70]

Financial costs

The life-cycle cost of a solar PV system consists of the initial investment, the value of operation, costs of maintenance, and the costs of battery replacement.[71] In the following part the initial investment, maintenance costs and battery replacement costs will be described.

Initial investment

The initial investment of a solar system is relatively high, starting with $300 up to $1000 for a 50 Wp system.[72] According to Mr. Jem Porcaro, an analyst for the Energy and Environment Group at UNDP, a solar home system in sub-Saharan Africa costs anywhere between the $500 and $1000.[73] Such a system usually provides enough power to, for example, light three to six rooms and power a black-and-white TV each night. However, the high initial investment is beyond the financial means of rural households in Uganda. The high initial costs for the purchase and installation are a major obstacle. Even in the wealthiest part of Africa, rural inhabitants cannot afford a solar system.[74] Funding is the most important hurdle faced by the rural poor (on the aspect of funding will commented in deliverable 3).

Because of the high initial costs, the solar system in first instance seems to be more appropriate for the use in these public buildings, benefiting the community as a whole, than for households. Besides, the structure of an average rooftop is not suitable for supporting the system. Solar systems could likewise power public buildings such as rural health centers and schools. Either way, donor or government-funding plays a crucial role in the purchase of solar systems in Uganda.

To determine the required equipment for a public building, many factors have to be taken into account. What are the size and budget of a building? And for what purpose will the solar technology be used? A school or clinic obviously needs more electricity than a small house. As explained in the first deliverable, the system size of a standalone system can be expanded by increasing the battery bank and the number and/ or size of the solar panels. A 200 to 400 Wp solar module is enough to power small refrigerators that is used for storing vaccinations for child immunization programs. The World Health Organization (WHO) considers this solution attractive compared to traditional initiatives. Therefore solar vaccine refrigerators have already been installed in hundreds of health clinics in Africa.[75]

The Global Cool Foundation and SolarAid, two UK registered charity organizations, operate in developing countries by installing PV systems in schools, community centres and health clinics. The systems they implement are usually 340-400 Wp in size, which is sufficient to supply small electrical equipment and provide for lighting.[76] Photowatt Technologies, a French company that is a developer and integrated manufacturer of PV products, also advocates for solar power in sub-Saharan rural areas. Their major community applications consist of schools and clinics. With a daily consumption of approximately 1,600 Wh a day, a school requires, in theory, a 500 Wp solar field. This is enough to supply a school with 16 lights, an overhead projector plus a socket to run small electric appliances. To supply clinics in Africa, the solar systems are extended to a size of 850 Wp. This is sufficient for a daily consumption of approximately 2,700 Wh/day, which equals the use of 16 lights, 1 examination lamp, 1 refrigerator for vaccines, 1 single sideband radio and 2 sockets to supply small electrical equipments.[77] With the price of approximately $8 per Wp, in Uganda the prices of the larger solar systems for public buildings as described above can start from approximately $ 4,000.

Batteries can make up of 40% of a solar system's total costs.[78] The costs of the battery's regulator usually represent around 10% of the total costs. Therefore, regulator prices are not as important a cost element of the solar system as the battery, solar module or installation costs.[79] The module price, representing 50 up to 60% of the total installed cost, is a key element in the investment of a PV system.

Operational costs

After the costs of the initial investment, costs for the purchase and for installation of the solar system, no further fuel costs are involved. Only small amounts of money need to be budgeted for maintenance, repairs and insurance.[80]

However, there is a significant additional cost concerning the replacement of batteries, since they do not last as long as the PV panels.[81] Ensuring sufficient revenue to periodically replace solar arrays batteries is the most important aspect for maintenance of a solar system.[82] Based upon a 'price per Watt hour' rating, the average cost for lead-acid batteries that are most commonly used is $0.23367/Watt hour to $0.2549/Watt hour.[83] However, since choice of technology and other technical factors are relevant, this is not a perfect measure.

<u>The solar system – total costs in steps</u>

Please note that the following steps are intended to help making a simplified cost-estimate and that the outcome does not constitute an exact representation of the total costs due to various factors that can increase or decrease the investment and/or operational costs.

<u>Investment costs</u>

Step one: *determine which devices are present or needed and for how many hours per day. This way the required Watt Hours in the public building can be calculated.*

Step two: *determine the solar array size by dividing the required kWh by the usable full sun hours in the area.*

Step three: *calculating the investment costs. For Uganda, the price per Wp should be taken between $8 and $12. Although the worldwide average retail price is much lower, this price includes a full PV-system, including all components and the installation costs. For a small panel, prices per Wp are therefore higher ($12) than they are for bigger systems where the same operational costs are paid. For the bigger systems a price of $8 per Wp is common.*

<u>Operational costs</u>

Step four: *The operational costs will mainly consist of the replacement of the battery approximately every 5 years. The price of the battery is generally about 15% of the total investment price.*[84]

<u>Socio-economic costs</u>

Increasing access to electricity is critical to ensure socio-economic development in developing countries.[85] It is however widely experienced that the introduction of solar systems in rural areas can only succeed if the technological concepts are appropriate to the cultural and socio-economic conditions.[86] Before implementing solar technology, the several social aspects have to be taken into account: During the implementation, all beneficiaries have to learn how to use and manage the solar system. Especially in the remote rural areas, the maintenance by local users is crucial to the sustainable running of a system. Local technicians need to be trained, as the lack of knowledge of the local population seems to be a major reason for the failure of achieving a sustainable operation.[87] Another important question that has to be addressed is how solar systems can be protected. Theft and vandalism must be prevented. After implementation, the technological, financial and social monitoring and evaluation is essential to ensure sustainability. Hereby, satisfaction and acceptation of customers are main indicators for success.[88]

Besides the health concerns of lead-acid batteries and the effort of ensuring social practices, the solar system itself has few socio-economic costs. But overall, the solar system can improve convenience, safety and the indoor air quality.

Personal story

Kaikara of 27 lives with her three children and husband in a hut in a small village in the Mbarara district of Uganda. During the day she is busy washing clothes, cooking and taking care of the cattle. Although she has always wished to continue her education and start her own small business in town, the nearby school enjoys no electricity as the whole region is without access to the grid. Evening classes therefore cannot take place as kerosene lights do not provide for sufficient light. With the implementation of solar technology in the school, the presence of sufficient lighting and even a computer would allow Kaikara to follow a course on entrepreneurship and give her and her family a brighter future perspective.

2.3.3 Comparison solar system and traditional system

Whereas PV generation costs are consistently decreasing, general electricity prices are expected to increase.[89] Analysis by several organizations such as Greenpeace, the European Photovoltaic Industry Association, and firms such as McKinsey & Company forecast that grid parity will be reached within twenty years.[90] Similarly, costs of fossil fuels are rapidly rising. Therefore, the solar system is slowly becoming a financially benevolent substitute for the generator. Certainly for those people in rural areas where there is no grid access, a solar system will be beneficial.

However, it is not easy to translate realistic economic analysis of PV systems into an accurate long-term cost projection for the number of complex factors that are involved.[91] Besides that, the cost structures of PV systems and diesel-powered system technologies are entirely different, which makes it hard to compare the technologies fairly. The initial cost of generators is low, but requires constant purchase of fuel and maintenance. The initial capital investment of a solar system is significantly higher. However, fuel is not needed and maintenance costs are relatively low.[92] The graphic below shows how the costs of both products are structured.

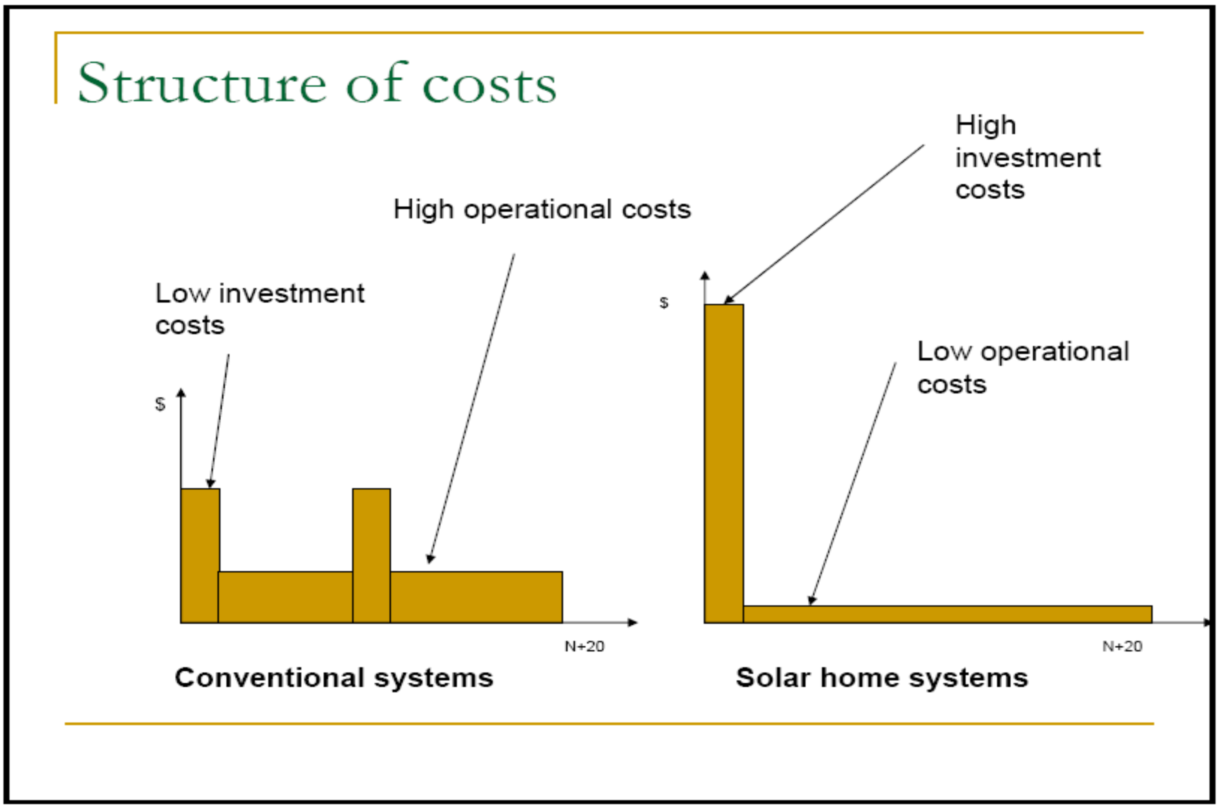


Figure 10: Conventional vs. solar systems: structure of costs (source: United Nations)[93]

The lifetime of the solar system is approximately twenty years while every five years the batteries have to be replaced. The lifetime of a diesel generator is approximately six years, but varies widely with the quality and frequency of maintenance.[94] Although the purchase of a solar system is more expensive than the purchase of a diesel generator, the latter could have a higher economic viability. The following boxes with a) a financial scenario and b) a personal scenario show how solar systems can help improve, apart from the environment, the lives of human beings in sub-Saharan Africa

How to calculate the total costs of a solar system

For the exact calculations in step 1 and 2 see the box on page 12.

1. Watt hours per day = Total Watt x Hrs per day

2. Watt peak solar array size = Wh per day / usable sun hrs per day

3. Investment costs = Watt peak x $8-$12

4. Operational costs (replacement of battery) = every 5 years

15% of the initial investment

Financial scenario

Below, the financial costs of a solar system for a small hospital in the district of Mbarara will be compared with the costs of a diesel generator, considering both investment and operational costs. This example approximates the costs based on the foregoing calculations and the load at which the generator or solar system has to operate.

The solar system

Step 1. *The small clinic in the district of Mbarara has to be supplied with 16 lights (11 W – 8 hrs/ day), 1 examination lamp (20 W – 4 hrs/ day), 1 refrigerator for vaccines (25 W -24hrs/ day), 1 single sideband radio (21 W - 24hrs/day) and 2 sockets to supply small electrical equipment (25 W – 2 hrs/ day). The daily consumption will approximately be:*

- 16 lamps x 11 W x 8 hours	*= 1408 Wh/ day*
- Examination lamp 20 W x 4 hours	*= 80 Wh/ day*
- Refrigerator (25 W) x 24 hours	*= 600 Wh/ day*
- Single sideband radio (21 W) x 24 hours	*= 500 Wh/ day*
- 2 sockets x 25 W x 2 hours	*= 100 Wh/ day +*
Total:	*= 2688 Wh/ day ≈ 2.700 Wh/ day*

Step 2. *The daily consumption of the clinic is approximately 2.700 Wh per day. Mbarara averages a daily amount of 4 usable sun hours. This means that the purchase of a (2.700/ 4 = 675) 675 Wp solar system should be sufficient in theory. In field conditions however, the real output is normally lower than the rated output. We advise to purchase a 750 or 800 Wp solar system.*

Step 3. *At the price of approximately $10 per Wp, the investment cost of the 750 Wp solar system for the clinic in Mbarara will be around $ 7,500.*
Step 4. *The operational costs for the battery replacement depend on many factors. Assuming that the price of the battery is 15% of the total initial costs ($ 7.500), this will come down to an extra $1,125 every five years after the installation of the system.*

The diesel generator

Step 1. *The hospitals load (see solar system step 1) is approximately 250 Watt in total.*

Step 2. *Small generators like the Honda EU1000iA have a maximum output of 1 Kw, which seems to suit perfect in this situation. This type of generator falls within the pricing range of $ 1000.*

Step 3. *The Honda EU1000iA has a consumption rate of ~0.3L per hour at +/- 250 watt.*[96] *The total Wh per day was 2.700 Wh. Divided by 250 watt ≈11 hours per day. 11 x 0,3L x $1,03 ≈ $3,40. The estimated fuel costs of the use of a diesel generator in the hospital are $ 3,40 per day.*
Please note that this would be the ideal situation, in which all devices are turned on. In reality this will not be the case as some devices are working 24 hours a day and others only for a few hours. In this way more diesel will be consumed.

Cost-benefit analysis

We assume a solar system has a lifetime of 20 years and a generator 8 years.
X = years
Solar system
Investment costs $7,500 + battery replacement $ 1,125 every five years:
Total costs in US dollars within a time span of 20 years= 7,500 + 1,125(X/5)*

Diesel generator

*Investment costs $ 1,000 + fuel consumption $ 1,241 per year (365 * $3,40):*
Total costs in US dollars = 1,000(X/8) + 1,241X*

Analysis

With the foregoing information the total costs after X years could be estimated. Although variable maintenance costs are not included, the following calculations of this scenario show clearly how the purchase of a solar system could be cost effective over time. In this case and under normal circumstances, after ten years the use of a solar system is already more lucrative than a diesel generator.

	Solar system	***Diesel generator***
Initial investment	*$7,500*	*$1,000*
After 5 years	*$8,625*	*$7,205*
After 10 years	*$9,750*	*$14,410 (generator replaced)*
After 15 years	*$10,875*	*$20,615*
After 20 years	*$12,000*	*$27,820 (generator replaced)*

Personal scenario

Saving money on the long term is not the only advantage. Dr. Ogwang, working in the hospital as a doctor and children's specialist, is also taking remarkable advantage from the installed solar system. Because of the shortage of doctors in rural Uganda, dr. Ogwang is indispensable in Mbarara. So is electricity, as a core element for the improvement of the children's health. Dr. Ojwang is now able to do his work without the inconvenience of noise and pollution caused by the preceding diesel generator. With cooled vaccines and sufficient light, dr. Ojwang is saving the lives of many children, in a healthy environment.

2.4 Solar water pumping systems versus conventional pumping techniques

The solar water pumping system and its beneficial effects have already been discussed in deliverable 1. However, when only taking the benefits into account, they have no practical value when technology is too complicated to implement or when the costs of solar water pumping systems transcend all the alternatives and other traditional forms of water pumping. When assessing the feasibility of a project, financial aspects play a crucial role. Money is often the decisive factor in whether or not a project enters the implementation stage or becomes successful. It is important to put the financial costs of both traditional and solar water pumping systems under close scrutiny and to analyze to what extent they are comparable with each other. Since the diesel generator water pumping system represents a technology that is "already highly developed and evolved",[96] one could argue that it is a well-established technique for pumping water in developing countries.[97] Consequently, the solar water pump has to prove its superiority over the diesel water pump in terms of financial costs.

Apart from diesel water pumps, hand and foot pumps also belong to conventional pumping techniques. However, these techniques will not be taken into consideration in this comparison. Because hand and foot pumps can merely operate on a small scale they form the cheapest option for low consumption rates and low pumping heads.[98] Therefore, they are the only and first option in poor areas that lack water supply. Nevertheless, when considering the comparison with solar and diesel pumps the problem lies in the fact that hand and foot pumps work with manpower instead of electricity. As a result, these pumps are not sufficient to pump water from deep heads or to ensure high flow rates of water. Furthermore, these pumps cannot supply water in dry seasons when the water level is decreasing.[99] Additionally, pumping larger amounts of water with a hand pump would require constant labour. Still, daily water flow rates could not reach those of water pumping systems that run on electricity. For example, diesel pumps that deliver an average flow of 10 or 32 m^3 per day are beyond the possibilities of hand or foot pumps.

Financial costs

Again, in the comparison between solar and diesel water pumps, the main question is how the financial costs of both systems can be calculated. The entire cost of a pumping system has a certain life expectancy in years that is made up of the capital cost, operating cost, and maintenance and replacement cost (M&R). The costs altogether refer to the so called 'life-cycle cost'. The capital cost is the initial investment that needs to be made, whereas operating costs and M&R costs pose future costs.[100]

For both systems the costs of the initial investment are dependent on the performance that is required. The systems can be sized differently, addressed to the pumping head and daily water demand. The size of the pumping head depends on the environmental circumstances which determine the depth of spring water underground. The deeper the natural water reservoir and the higher the daily demand, the more kWp is needed. For example, for a pumping head of 26 metre and a daily demand of 41 m³, 1.61 kWp suffices, while for a pumping head of 87 metre and a daily demand of 52 m³, 5.8 kWp is required.[101] The required power determines the size of the diesel engine for diesel pumping systems and the amount of Watt peak the solar panel of solar pumping systems needs to have.[102]

The operating costs of diesel pumping systems consist of the diesel consumption including transport costs that are made in order for the pumping system to operate. For solar pumping systems, no fuel is required.

The maintenance costs for diesel water pumping systems are the sum of the costs of engine oil, filters, brushes, diaphragms, valves, rotor, impellers, labour, and the components that need to be replaced after a certain time, etc.[103]

In the following paragraphs the different costs for diesel water pumping systems and solar PV water pumping systems will be examined and applied to both systems. In the last section, the final comparison between solar and diesel pumping systems will be made.

2.4.1 Diesel generator water pumping system

<u>Financial costs</u>

Investment costs

The fact that diesel water pumps are widely used certainly has to do with the fact that capital costs do not form a high barrier as is the case with solar water pumps. A study conducted in 2006 on behalf of the Namibian Ministry of Mines and Energy, found that the capital costs of a diesel pump that delivers 10m³ per day at an 80m head formed 10% of the life cycle cost.[104] All in all, capital costs are formed by the generator, the motor/pump, accessories, and installation costs. The cost of a generator depends on how much electricity it produces. To give an example, a 2 Kw, 50m pump head costs $1000. Installation costs in the United States of America are $500 US$. Moreover, it is important to note that these costs are dependent on labour costs. In developing countries, installation costs are significantly lower which is why, for example, in Bangladesh installation costs are only $100 per pump. In a water pumping system, the engine is mostly incorporated in the pump. Therefore, they are both included in the price. According to the article of Kala Meah, the price of an engine and pump together comes to $750. Accessories (filters, brushes, diaphragms, valves, rotor, impellers) cost around $200.[105]

Operational costs

When assessing the long term costs, the picture shows a different view. According to a study done by the Namibian Ministry of Mines and Energy, M&R costs and operating costs form with a 90% the vast bulk of the life cycle cost.[106] This does not come surprisingly given the fact that, normally, the diesel generator needs to be replaced every four to five years. Furthermore, diesel needs to be bought repeatedly and transportation costs need to be considered, since the fuel has to be transported from another location. In case a vehicle that runs on gasoline is responsible for transportation, extra fuel costs are involved. If a manual vehicle is used for obtaining the fuel, transportation costs are lower. Besides, the costs of transportation also depend on the situated distance of a gas station. Moreover, maintenance costs should not be neglected neither. Usually, the generator requires reparation two to three times a year. Reparation of the engine requires intense and skilled labour. This factor contributes to the diesel water pumping system being a costly solution in the long run.[107]

2.4.2 Solar PV water pumping system

Hand pumps and pumping systems powered by diesel have been used for decades. However, hand pumps cost a lot of men power and do not offer great quantities of water; diesel pumping systems have been criticized due to the environmental damages they cause and the obstacle of requiring diesel on a regular basis. Pumping systems relying on renewable energy sources might solve these problems with the more traditional pumping systems. Options for pumping systems relying on renewable energy sources include PV pumping systems and engines working on wind generated electricity or biogas. The PV systems have advantages over these systems in meeting the need of remote communities, for a lot of isolated zones in African countries have great sunlight exposure and this energy source is more available than wind or even biomass or biogas in many places.

The currently existing solar water pumps are mainly used for village water supply, livestock watering and irrigation. Although PV pumping systems are not cost effective compared to electricity supplied from the electric grid, the costs for standalone PV pumping systems can compete with pumping systems powered by diesel.[108] In PV water pumping applications, the cost of water is affected by its system productivity, interest rate, capital investments, and operating and maintenance cost.[109] In this paragraph the costs of standalone PV pumping systems will be discussed.

Investment costs

The costs of the pumping systems relying on solar energy themselves are highly dependent on the characteristics of the system being used. The different types of PV pumps currently available on the market can pump up to 200 metre head. The differences in head determine the flow of water which the pumping system can produce. For example, there are pumps that deliver a flow of 10,000 litre water a day at 100 metre head or 20,000 litres a day at 50 metre. Although there is no limit to how powerful a solar powered pump can be, the pumps seem to be more cost effective when they are smaller. This is because PV systems have little or no economies of scale, and all other alternatives have strong economies of scale. For example, a small solar pump requires less than 150 W and can lift water from depths exceeding 65 metre at 5.7 litres per minute. In a ten hour sunny day it can lift 3,400 litres of water which is enough for several families.[110]

The high initial costs of PV water pumping systems contain the PV solar modules and the pump itself. Because the pumps connected to the solar modules are highly differential and thus have very differentiated costs, specific examples will be given in the next paragraph. The estimated costs of solar modules that are connected are estimated by Ramos and Ramos in 2009 at 5000 euro (6174.48 USD) per kWp. Because of the rapidly developing technology regarding the field of solar power these costs are estimated to decline over time.

The initial capital cost also depends on whether the pumping system contains a battery. The capital cost of a battery is quite high and it is questionable whether it is useful to let a pumping system operate at night. The estimated costs of a battery by Ramos and Ramos are 200 euros (246.98 USD) per kWp. A cheap and simple solution could be found in placement of a water reservoir to preserve excess pumped water. In this manner, the costs of a battery could be eliminated completely.

Operational costs and maintenance

It is clear that PV pumps avoid uncertainties associated with fluctuating availability of the price of diesel fuel, and thus the operating costs are zero.[111] The PV technology nowadays is developed in a way that the technology is very reliable, the life expectancy is very high: 25 to 30 years, and needs little maintenance. Within the technology, water pumping has long been the most reliable and most economic application of solar electric systems.[112] In general, a PV solar pumping system has little operating and maintenance cost, because after placement the system can work on itself. However, always certain maintenance costs remain. As mentioned before, the initial cost of batteries that could be used in the PV water pumping systems are high and easily avoided through the use of a water reservoir. The elimination of batteries from the system eliminates most of the maintenance costs of the system as a whole, but also the maintenance cost of the pump. Moreover, the PV pumps only need minimal attendance and can often work unattended for a long period of time as do the solar modules.

The life expectancy of the components of the PV water pumping systems is high. The solar modules produce energy up to 25 years and the pumps have a life expectancy varying from 5 to over 10 years. It is also valuable to mention that most of the pumps are designed to be repaired in the field. Unless the pump controller fails, the only maintenance is cleaning the solar modules every 2 to 4 weeks, which can be done by non-skilled local labour.[113]

	Initial cost	Maintenance cost
Pv modules	\$6174.50(5000 euro) per kW peak	\$61.75(50 euro) a year per kW peak
batteries	\$247 (200 euro) per kW hour	\$2.47(2 euro) per year per kW hour
converter	\$617.45(500 euro) per kW	\$6.18(5 euro) per year per kW

Table 3: Estimated costs of PV pumping systems, 2009 by Ramos and Ramos [114]

Socio-economic costs

In the part of the paper concerning environmental aspects and socio-economic costs of diesel generators, the costs other than financial costs regarding noise and pollution were already mentioned for both the diesel pumping system and solar pumping system. Since the social-economic costs of PV solar systems and diesel pumping mainly rely on the differences from traditional hand pumps, these will be discussed in this paragraph.

In the first place, prior to installation, the impact of an enlarged water supply on communities should be considered. Since diesel pumping systems and PV pumping systems are capable of pumping at more head and provide a constant water supply, water pumping and fetching have become a social event, if this custom will be eliminated, the community could feel this absence as a negative impact of the pumping system. Moreover, the emergence of a new water source or increased water supply could influence gender relations in rural areas. Because the supply of water for a family is mainly seen as the responsibility of women, their social position might change in the community. Also the social constructed responsibility of water lies with women. Therefore, men might not want to participate in maintenance activities concerning water activities.[115]

In the second place, socio-economic costs for both diesel pumping systems and PV pumping systems are raised by theft protection costs. Because the systems as a whole, or valuable parts such as the solar panels, are seen as high value objects they need to be protected to ensure sustainability in the pumping system. Naturally, this brings protection costs along.[116]

Also, the shift from hand pumps to either diesel water pumping systems or PV water pumping systems implies that, since the use of hand pumps is very time consuming, the people living in rural areas could feel an increase in availability of their spare time. This could lead to more community interaction in important social events. Besides, more the time can be spend on (small) economic activities such as private farming. So, if men and women are convinced of the usability and reliability of the solar water pump, the social cohesion within a community might grow after implementation of a water pumping system.[117]

Personal Story

The installation of a solar water pumping system has made life easier for Nyombi, who lives with his family in a remote village in Uganda. Thanks to the installed solar water pump, Nyombi and his family are able to get their clean water from a nearby reservoir that is always filled with fresh water. On a sunny day, the pump provides up to 30 cubic meters of water. This sufficiently covers the water demand of the village, where a little less than 1,000 people are living. According to UNDP standards, a person needs 20 litres a day. So, Nyombi, as all other villagers, have 5/10 cubic meters of water left to use for other purposes such as irrigation. Since the installation of the solar pump 10 years ago, their agricultural activities have become much more stable and predictable. The stable availability of water protects the villagers from crop failures that often occur in the dry periods. Nyombi can be sure that there is enough food for the needs of his family, and is able to sell a little on the local market. This provides him with a higher and stable income, which made it possible to let all of his two children go to school.

Nyombi explains that his wife had to walk for an hour to get water when there was no solar pump. There was only a hand pump that did not supply a lot of water, and the water that was brought by his wife was not enough to meet all their needs in regard to cooking, washing, cleaning etc. Apart from that, the hand pump did not supply water in dry seasons. The solar pump, on the contrary, proved to be very reliable. Nyombi heard from a friend that in their community a diesel pump was installed. His friend told him that the diesel pump is not very reliable. At first, the system worked, but the villagers were often lacking the fuel to keep the pump running, since they either lacked the money to buy it or had problems with transporting the fuel to their village. The supply of water was further interrupted because the engine stopped working very often. A technician, who lives in a town not far away, is able to repair it, but nobody felt responsible to pay the technician. It also took some time to hire the technician. Since three years, the diesel pump installation is useless because the technician found that the engine needs to be replaced, and nobody can afford to buy a new diesel engine.

2.4.3 Comparison of diesel and solar pumping system

After having mentioned the most relevant costs of the separate systems, a comparison between the life cycle costs of both systems will be drawn. The study revealed that the systems have important differences in their centre of gravity for their cost. As the highest costs of the PV system are situated in their capital cost, the initial investments are great. However, other costs that play a role in the future, such as operational and maintenance costs are strikingly low. As a result, the PV system becomes a feasible solution compared to the diesel pumping system, where costs can run up quite quickly.

This finding is illustrated below in graphs 2 and 3, which were published in a report conducted on behalf of the Namibian Ministry of Mines and Energy. Figure 3.7 gives the life cycle costs (in Namibian dollars) for the solar and diesel pump at different hydraulic loads.[118] At a hydraulic load of 500 m^4/day, the life cycle cost of the solar pumping system lies at only 20% of the life cycle cost of the diesel pumping system. As the diesel pump is more cost effective at higher hydraulic loads, this percentage is rising accordingly. However, the hydraulic load that is expected of a solar water pumping system mostly falls within the range of less than 1000m^4/day. For example, the Solar Electric Light Fund claims that the pumps they have used for agriculture or village water supply did not require a hydraulic load higher than 1000m^4/day.[119] Therefore, it can be assumed that in real world scenarios the life cycle costs often come at a fifth of the costs being involved in diesel water pumps. Consequently, as is illustrated in figure 3.8, it is often the case that the breakeven point, which is the point at which the costs are equal, occurs already after two years.[120]

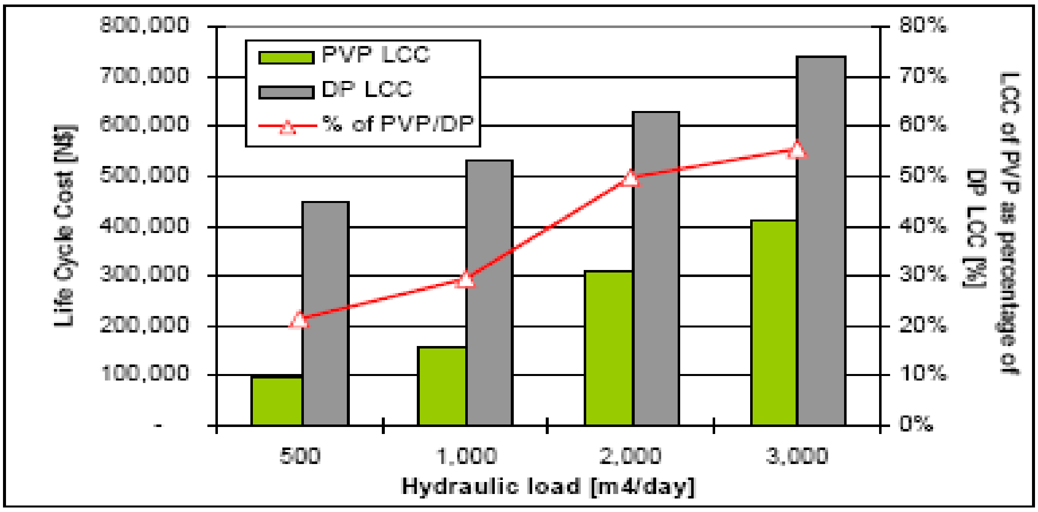


Figure 3.7: Life Cycle Costing as a function of the hydraulic load

Graph 2.

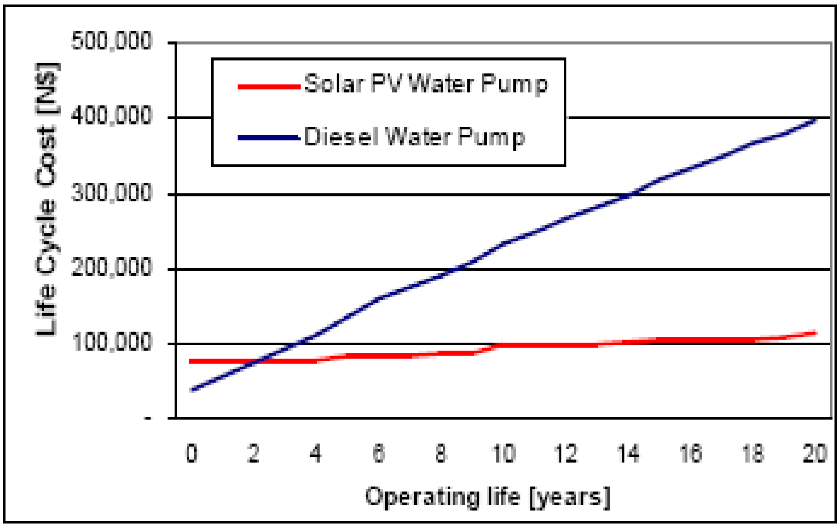


Figure 3.8: Typical years to breakeven graph for PV pump vs. a diesel pump

Graph 3.

Last but not least, it should be mentioned that the water demand at the site of the pump should be taken into account. In situations where the water demand significantly varies or where there is no constant water demand, diesel pumps may present a more cost effective solution because the initial capital cost is lower and pumping is only incurred when needed. The solar water pump, on the other hand, pumps water as long as the sun provides the system with electricity. In other words, the diesel pump has an advantage of flexibility over the solar pump.

A change in water demand can be addressed immediately by deciding to run the diesel engine for a longer or a short amount of time a day.

2.5 Kerosene and biomass versus Solar tools

In this part of the paper the financial and socio-economic costs of kerosene and biomass will be outlined. The comparison will focus on the extent to which solar energy could form a substitute for these energy sources. The reason for examining kerosene and biomass in a separate chapter is that the use of these fuels is of significant importance in rural areas. Although kerosene and biomass could be used for the same purposes, a separation is made between the purpose of lighting and cooking: kerosene will be linked to lighting purposes and biomass to cooking. In the first place, the solar lighting systems will be examined and compared with traditional sources of lighting. In the second place, the comparison will be made between cooking on biomass and solar cooking solutions. Finally, a short conclusion will be given.

In order to form an equation between solar and traditional lighting, the traditional sources will be examined first, followed by the financial and socio-economic costs of the portable solar lighting tools. Finally, a balance will be demonstrated between solar and traditional lighting sources.

2.5.1 Traditional lighting in rural Uganda

<u>Financial costs</u>

Biomass and kerosene are the main sources used for lighting (around 90% of the homes use these sources).[121] In 2002 an indication showed that a total of 42,400 toe of kerosene is used by households each year, which is available through petrol stations and some retail outlets.[122] Over the last few years, the price of kerosene has increased with a faster rate than the annual fuel price and will possibly be more expensive than petrol in the future.[123] Currently, the price of kerosene stands at around $1.03 per liter.[124]

<u>Socio-economic costs</u>

Although in rural areas kerosene seems to be the cheapest and easiest solution, the disadvantages of this type of fuel are inescapable. These disadvantages include health considerations and the lack of sufficient lighting for evening activities. According to the World Health Organization there are more than 1 million deaths every year attributed to kerosene lamps; 62% of the people that die are under the age of fourteen. Besides, as mentioned before environmental aspects, kerosene lamps are annually responsible for at least 100 million tons of carbon dioxide emission.[125] Especially children suffer from the disadvantages of kerosene fuel. In South Africa, between 40,000 and 60,000 children are poisoned each year after ingesting paraffin/kerosene.[126] The reason for the high death/ illness rate of children is the lack of protection and ventilation of the area where the fuels are used for cooking and lighting. In Uganda and many other African countries, kerosene is used in wick lamps which are causing infants and toddlers being burned and scalded.[127]

Moreover, the brightness of the light produced by the burning kerosene is not sufficient for studying or working at night. A study by the foundation of lighting Africa in five African countries, found that the main indoor nighttime activities that are significantly hindered by poor lighting are reading, doing homework and preparing food. Going to the toilet, tending to livestock and visiting are the main outdoor night-time activities that are significantly hindered by the lack of lighting and which would be considered priorities in the distribution of light. The main problems these households encounter without access to qualitative lighting, is the insecurity to go outside, the inability to do homework, and the postponing of tasks to day time.[128]

The following background story demonstrates the socio-economic costs of kerosene and its major impact on an average family in rural Uganda.[129]

Text and photo by Alex Mugarura in Kishasha, Uganda (www.lighting.philips.com)

It is just over 7pm in Uganda when Kyomugisha Mackline and her two children are preparing to go to bed. The reason for this is not sleep, but darkness.

Kyomugisha (35, and her daughters Kemigisha and Kyomuhang, live in a remote Ugandan village of Kishasha, in Kashari county of the Mbarara district. A few minutes to 9pm, the village is dead quiet. Only a few dogs can be heard as they bark probably from the neighboring village.

Back in her three roomed house, Kyomugisha lays inside her bed awake. She has nowhere to go apart from her bed because darkness reins her house like it does in almost all families in her village.

Kyomugisha can hardly afford buying enough kerosene to light the traditional Etadoba lamp which is the only source of light in her home at night. The only option her family has is to eat supper before the sun sets to benefit from its natural light.

Kyomugisha's family is one of millions of rural families in Uganda that rush to accomplish all their daily chores before it gets dark. They simply cannot afford paying for artificial light. Only three percent of rural households in Uganda have access to the electricity grid.

2.5.2 Solar lighting

This part of the chapter will contain the financial and socio-economic aspects of the purchase and use of portable Solar lighting systems. These systems have been described in deliverable 1.

<u>Financial costs</u>

The prices of the portable lighting differ per brand and company that produces them. Overall, one could say that the cost of purchase lay between $10 and $20. The maintenance of lamps differ and depend on usage. In addition, the maintenance of the products also depend on whether the solar panel is integrated into the lamp, or if the panel is working separately. Besides, (absence of) available knowledge of technology influences the lifespan of the product. Although the mentioned portable systems require less technological expertise than the solar systems explained earlier, training on how to use the product is still necessary in order to guarantee long term custom and utility. The costs of training depend on the type of project, duration and the amount of people involved. Later in this part an example of a solar lamp project will be provided, including estimated costs.

<u>Socio-economic costs</u>

One has to consider the circumstances and needs of a family, health center, and school facility when taking the purchase of solar lighting tools into consideration. A model should be set up that indicates the amount of light that is needed per day, depending on the needs of the facility. In the comparison between solar lighting and kerosene, examples will be given on this matter.

An example of an already implemented project of solar lamps in rural communities has been provided by the Koru Foundation. The Koru Foundation has the aim of tackling poverty through a renewable energy conducted project in Uganda, which has been later transferred to Trocaire. Trocaire invested in 285 lamps for the poor and disabled in the Lucinda and Kanine villages of the Pader District in Uganda. From their experience ‘the lamps will increase self-sufficiency as well as reducing people’s reliance on expensive and harmful imported paraffin and candles’.[130] This project also stresses the importance of training and educating people in the efficient usage of the lamps. According to the final report of Trocaire, with the investments of 285 lamps, including the training in Solar and repair at community level, a total of $2750 has been spent on the project.[131]

Figure 11, Solar lighting in a household Source: Koru foundation

2.5.3. Comparison solar lighting and traditional lighting

Information on the financial and socio-economic aspects of solar and traditional lighting has been given. A financial comparison can be made on the short, or on the long term which, we will elaborate on below.

Kerosene is available in every petrol station and many retail outlets. On the other hand, the price of kerosene is rising rapidly and the majority of the Ugandan population with low incomes find difficulties in purchasing the expensive fuel. Besides that, the use of kerosene contributes to serious health issues concerning burns and poisoning.

When exposed to these risks on an early age, the consequences are severe and could lead to death. In contrast, solar lighting is clean and user friendly. It provides bright light that enables children to study. Some generate up to five to six times more light than kerosene.[132]

The price of kerosene is relatively high and likely to increase. On the short term therefore, it is an expensive purchase. When considering the introduction of a solar lamp in a household the following calculation can be made:

We assume the price of kerosene to be $ 1.03 per liter in 2010, and the use of one rural family (depending on size and activities) approximately 1 liter per week. Consequently, the expenses for one family on kerosene will be $ 4.12 per month (1.03x4) and $ 49.44 per year (4.12x12). When the option of solar lighting comes into view, the costs differ from $ 5 – $ 20 per lamp. When taking a lamp of $10, initially rural households will consider one lamp per family. After less than 2.5 months (4.12 x 2.5 = 10.3) the costs of kerosene exceeds the purchase price of one solar lamp. In this manner other prices of solar lamps can be compared with the price of kerosene, taking into consideration the family size and use.

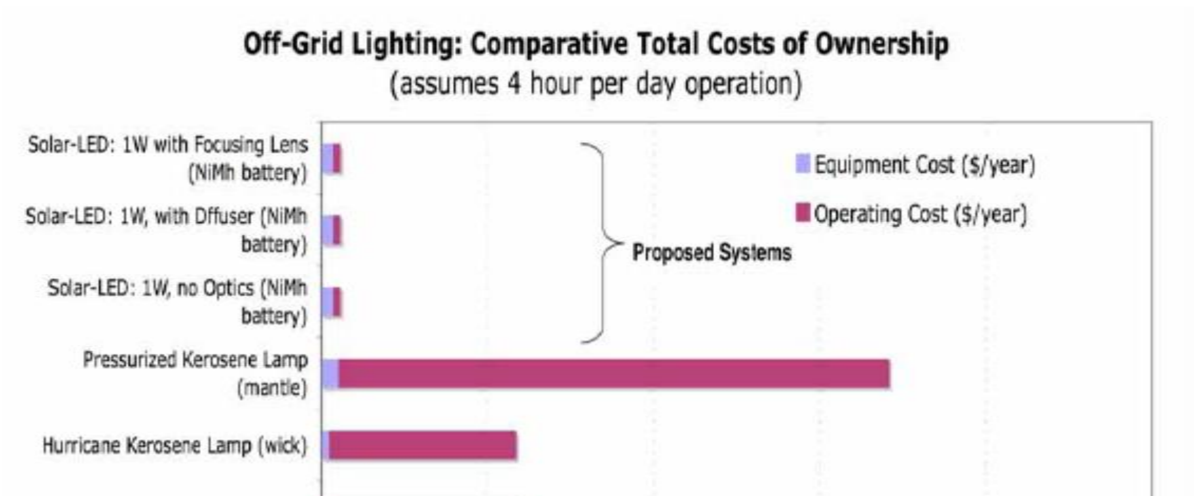
<u>The following calculation can be made for a school</u>

The same type of calculation has been made for the previous example. An average rural school that lacks electricity from the grid is obligatory to use other forms of lighting such as kerosene. With a dollar price of 1.03 per liter, a school is likely to consume approximately five liters a week. Consequently, the expenses will be $ 5.15 a week and $ 20.60 per month and $247.20 year. With the introduction of 5 solar lamps, of each 10 dollars, the investment will contain $50. After 2.5 months the expenses of the 5 solar lamps will be zero.

The calculations point out that the purchase of one solar lamp is more expensive than the amount of dollars needed for kerosene on the short term. However, the example shows that on the long term the costs of kerosene will transcend the costs of solar lamps. Nevertheless, we have to bear in mind that maintenance of a solar lamp depends on the degree of accuracy of use by its owner. It is likely that every five to ten years a new lamp needs to be purchased. Besides that, to forestall the lamps being damaged relatively quickly, an investment has to be made by teaching the owners how to use the product and how to circumvent possible problems.

A complement is added in order to compare the prices of traditional lighting energy sources to solar energy. The high upfront costs of Off-Grid Lighting are the only obstacle herein; however, these could easily be circumvented if a loan system would be introduced.[133]

Graph 4.



Personal scenario

There is no electricity throughout most of Northern Uganda, thus young people find it very difficult to do home assignments once sunset arrives. Dembe, the oldest son of a family of five kids, is continuing school since the many years of war, and since the 'Lords Resistance Army' disrupted his family's life. Dembe uses a kerosene lamp in his hut, which gives off a great deal of smoke and provides poor light. Besides, the family also uses kerosene for the several activities around the house in the evening. Dembe's family received a solar lamp, and has been using it for the past few months. The solar lamp has to charge in the sun for approximately 5 hours and produces bright light in the evening for 4 up to 6 hours. Dembe is delighted with the obtained solar lamp, because it is much easier for him to make his home assignments. Plus, the side effects of the kerosene are omitted. Moreover, his family does not have to spend the weekly $1 to $2 on kerosene. These savings make a big difference to the family that has a low income. Now there is more money for basic necessities and education opportunities for Dembe and his younger brothers and sister.

2.5.4. Traditional cooking

Building on the insights of the previous section, this part will continue with elaborating on the use of biomass as a traditional source of energy. The first part will clarify the significance of wood in a Ugandan rural society and the second part will focus on the advantages of cooking on solar energy. Finally, the comparison will be made between the financial and socio-economic aspects of the traditional source and that of the solar 'Cookit' and 'Solar box', mentioned in the first deliverable.

Financial, socio-economic costs

Electricity is used for cooking by only a small minority. According to the article 'Energy profile of Uganda', the Ugandan census of 2002 reported that 81.8% of Uganda households (22.4% urban households and 91.4% of rural households) use firewood for cooking and another 15.2% charcoal (66.6% urban households and 7.0% of rural households). Combined, this totals to 97% of Ugandans using wood or charcoal (89% urban households and 98.4% of rural households).[134] Moreover, a total of 13.5 million tons (5.23 million toe) of wood are used by households in Uganda, outstripping supply by 3.8 million tones of wood per year.[135] As a result, wood is becoming increasingly scarce. Due to this scarcity, environmental problems occur concerning deforestation, erosion, and a decrease in quality of the soil, as described in environmental aspects.

Relevant to cooking activities, the scarcity of wood requires people to spend more time and effort in collecting it. This situation applies not only to Uganda but is relevant to other countries in Africa as well. According to a report on household energy and DMGs between 1990 and 2003, Ugandans spend on average 2 hours a day on collecting wood. In Niger this reaches up to 4 hours, Ethiopia approximately 3 hours, Namibia 1.5 hours and in Nigeria less than half an hour.[136] Although the fact that in most rural areas wood is gathered, in urban areas it is usually purchased with prices ranging from 16 (19.76 USD) to 38 Euro (48.93 USD) per toe.[137] Taking the market prices, wood is the cheapest form of energy (20-45 dollar/toe) followed by charcoal (250 dollar/toe), Kerosene (1,000 dollar/toe).[138]

Due to the large amount of people in rural Uganda who use traditional stoves (over 90%), people are heavily dependent on wood and charcoal.[139] The high usage of these fuels is causing dependency. Therefore a change in fuel seems not likely to happen in the nearby future. However, the use of wood for cooking generates tremendous health problems for those subjected to the smoke. According to the report on the household energy and DMGs, indoor smoke is one of the underlying causes, and to blame, for nearly 800,000 child deaths annually.[140] Moreover, more than one third of the child deaths, 35,000 deaths, occur on the African continent. Another 288,000 child deaths occur on South-East Asia.[141] A study of the World Health Organization has indicated that with reducing these alarming numbers, the air pollution in homes should decline. This could be achieved by providing people the access to cleaner fuels and access to improved stoves.[142]

2.5.5. Solar cooking

Financial costs

The purchase cost of solar cooking differs per product. The prices of a solar cooker range from $5 to over $200, depending on the size and advancement of the cooker. These relative expensive cookers have no purpose in third world countries. Besides the high expenses, they are too big and too clumsy to be a sufficient tool for the poor. The solar solutions for cooking which can be applied to Africa, therefore costs at most $30.

The costs of the previous mentioned saving-wood stoves depend on the material they are made of. The maintenance costs of solar cookers depend on how the solar cookers are used. When information is provided on usage and maintainability of the product, the cooker should last for years. Important maintenance factors of the solar cooker and box have been outlined in deliverable 1.

2.5.6. Comparison solar cooking versus traditional cooking

Evidently, a solution for the problem concerning the tremendous wood usage which ensures scarcity of wood and poor health conditions for people, should be seriously considered. Generating wood for cooking in rural areas is cheap, since it is assumed to be a costless source of energy. Accordingly, it could be assumed that no initial costs are involved for those in rural areas. However, the hours spent on gathering could be spent on economic and study activities. With less time lost in collecting fuel and less health problems, children will have more time available for school attendance and homework. Besides, alleviating the drudgery of fuel collection and reducing cooking time will free women's time for productive endeavors, education, and child care.[143]

Moreover, reducing the time and distance that women and girls need to travel to collect fuel will reduce the risk of assault and injury, particularly in conflict situations.[144] Concerning health, it could be concluded that due to the smoke of the fires, especially children suffer heavily. This turns out in a tremendous amount of deaths every year. Therefore, a less polluted home can improve the health of new mothers who spend time nearby the fire after having given birth.

The costs of purchase and maintenance of the solar cookers are higher compared to cooking by using wood. By taking these socio-economic costs of wood into consideration, solar cooking, together with the wood savings stoves, seems to be the most sustainable solution for the problem of energy shortage in rural areas. When examining the solar option, the result is that no wood is required for cooking and this will save time, health risks, and trees. In our world of rising fuel prices and extreme deforestation the contribution of solar cookers as a reliable and sustainable energy source should not be underestimated.

Personal scenario:

Nabukenya is a woman living in a small hut nearby the rural village Ngoma. She is taking care of five children. Two of them are from her sister, who died shortly after her husband died of AIDS. Her own husband is often away from home, searching for jobs. With having seven mouths to feed, she is obligated to spend a lot of time on cooking and gathering wood. Every day, up to 5 hours she spends on these activities. Two of the oldest children, an eight year old girl named Keisha, and a boy of 10 named Kalungi, often join their mother in collecting and cooking, trying to support her in taking care of the family. Nabukenya explains how she benefits from the solar cooker which has been provided for several families like hers in the region around Ngoma.

'I feel always guilty for my children to leave them at home alone and taking two with me for gathering wood. Since I cannot financially rely on my husband I feel forced to create my own income. With the solar cooker, I have more time left. Instead of five hours of collecting and cooking, it now takes 2 hours without any collecting. Now, I could earn a little money to let all of my children go to school. My children feel much saver in the hut, since the danger of smoke from the fire has been abandoned by using the solar cooker. Moreover, the Solar cooker has been proven very easy in use. Burns are not common anymore and the food has the same good quality. I feel blessed'.

One might say that is it difficult to exactly provide a comparison of financial costs for kerosene, biomass, and solar energy. Many factors including the environment, economic situation, and available technological knowledge are influencing the costs of purchase and maintenance of solar products. Although the use of traditional sources of energy has severe consequences for people's health and level of education, the transition to solar solutions is hindered due to high purchase costs.

Albeit the costs of kerosene will be outweighed on the long term, the lack of knowledge, and wrong usage that is likely to harm the product, contains the main argument not to switch to Solar. A shift needs to take place from the focus on the short term expenses to long term sustainability. Only then a real step forward to development will be made to where the introduction of solar energy will be the face of increasing prosperity.

2.6. Conclusion

It has evidently been shown that the purchase, implementation, and maintenance costs of solar energy in general entail several important considerations. First of all, the purchase of the systems, from a solar light of $20 to a PV system of $1000, has been shown relative expensive compared with traditional energy sources. The average income of a person in Uganda does not allow for such expenditures. Consequently, the high initial investments need to be made by financially strong institutions.

Although purchase and implementation contain a great investment, the maintenance costs of a solar system are significantly less. This leads us to the conclusion that for traditional energy, in the context of the generator, the initial costs may be cheaper than the solar systems, but on the long term the costs often exceed the maintenance costs of solar systems. In other words, the operational costs of a generator are high. They involve daily use of fuel and need to be replaced after 5 to 10 years. Solar systems, on the contrary, do not require any fuel and are supposed to last for at least 20 years. Replacement of the batteries, which normally occurs every 5 years, forms a significant cost for the solar system. Nevertheless, on the long term the solar system seems to be an economically viable option.

The same accounts for the comparison between diesel pumping systems and solar PV pumping systems. Examination of the financial costs involved in solar powered pumping systems revealed two important findings: the initial capital costs are very high, whereas future costs, which are formed by operating costs, maintenance, and replacement costs are significantly low. On the whole, even though the initial investment of solar water pumping systems is high, making it an expensive alternative to energy sources run by traditional energy, solar systems bring about no additional cost of maintenance or fluctuating costs of purchasing diesel. As a result, on the long term solar water pumps are in most cases less expensive than diesel pumps.

Notwithstanding the fact that maintenance costs of solar systems are assumed to be relatively low, effort needs to be put in to guarantee the long time operation of the technology. Instructing the local people in using the technology properly is of main importance for the lifespan of solar technology.

Regarding the comparison between kerosene for lighting and solar energy, portable lighting systems will be financially feasible on the long term. Therefore, to lighten rural areas on the short term, the price of a solar system is more expensive than the use of kerosene lamps. However, on the long term, the costs of kerosene lamps will transcend the costs of solar lamps.

When looking at the comparison between biomass for cooking and solar cookers, solar energy is of significant importance for the weakest group of Africa's population: women and children. Even though, there are no initial costs involved in generating wood for cooking in rural areas, there are socio-economic and environmental costs involved. These costs would be avoided by using the solar cookers. Although their initial price and maintenance costs are higher compared to wood, people's well-being and a stable environment should come first.

Taking the implementation of solar energy into consideration for any type of application, the local technological knowledge is of vital importance. The initiative taker should invest time in training locals. Only then, will receivers fully understand the use of the system as well as become aware of how the use of solar energy will improve their personal life and the life of the community as a whole. Besides the financial costs, the improvement of health related issues and the education level of children is of significant importance. Solar systems are clean, provide bright light, and are a reliable energy source for rural clinics and schools.

In the end, the obvious socio-economic and environmental advantages of solar technology should be able to outweigh its high upfront costs and make human development a priority. Unfortunately in reality this is often not the case. The supporting NGO's and governments still hesitate to cover costs on the long term, which may not be worth the benefits on the short term. Thus, the accent should shift from low short term costs of energy products to the important value of sustainability that Solar products have over traditional sources. Only then a real step forward to development will be made. Therefore, the introduction of solar energy could be the face of increasing prosperity.

2.7. Final Conclusion

In sum, the goal of this research has been to point out the most important issues regarding the implementation of solar energy. It indicates the feasibility and possibility of solar energy in general. By making it more specific and understandable, examples of implementation have been demonstrated by applying the PV systems to different situations.

The needs of people in rural Uganda have been examined in terms of their social and economic situation. From here, it has been shown to what extent solar energy is able to positively contribute to the development of rural areas in Uganda and ultimate to Sub-Saharan Africa. By providing an overview of solar technologies, different uses of this form of energy has been shown. Solar technologies are able to provide electricity for several applications: to lighten and provide access to water in households, schools, and health centers. This could finally contribute to an overall better standard of life, education, and healthcare. Besides that, the difficult conditions that could hinder the implementation of solar systems have been acknowledged. Identified difficult conditions in rural Uganda, but also in general for countries in Sub-Saharan Africa, are theft, corruption, lack of knowledge, and constraints on the (local) market.

Furthermore, a cost-benefit analysis of solar energy versus traditional energy sources on environmental, financial, and socio-economic levels has been given. When the environmental level is considered, the impact of solar energy tremendously differs from the impact of traditional energy sources on the environment. The use of solar energy does not entail any pollution and is assumed to be a reliable source of energy. However, when observing Uganda's consumption of fossil fuels and the high use of biomass by the (rural) population, we see that both put significant pressure on Uganda's natural habitat. Moreover, Uganda's production of greenhouse emissions and the country's dependency on depleting fossil fuels ensures the traditional energy sources as unsustainable and therefore not reliable in terms of future prospects. Especially the use of biomass as a primary source of energy and its increased consumption leads to high levels of deforestation in Uganda. By addressing the use of batteries in Uganda, one can conclude that inappropriate recycling of lead-acid cell batteries will damage the environment as well. These batteries are easily thrown away by the people. On the other hand, the batteries used in solar technologies have a relative long lifespan and cause minor contamination provided that they are appropriately recycled.

Furthermore, the cost-benefit analysis focused on the financial and socio-economic aspect. This was realized by means of comparing diesel generators with solar systems, diesel water pumps with solar water pumps, and kerosene and biomass with solar energy solutions. The comparisons between diesel generators with solar systems and diesel water pumping systems with PV pumping systems have shown virtually equal results. Even though, the initial investment of diesel generators is lower than the initial investment of solar systems, diesel generators involve daily use of fuel and high maintenance costs. Solar systems, on the other hand, do not require fuel and their maintenance costs are relatively lower. This makes solar systems an economically viable option on the long run in comparison to diesel generators.

Moreover, the use of solar energy brings socio-economic benefits for a rural African society. Concerning solar water pumps, which provide for more water than diesel water pumps, the social position of women is likely to change in their community, since they are often kept responsible for the family supply of water. Besides, because solar water pumps reduce threat of water shortage, families will be able to spend more time on economic activities and schooling. When considering the comparison between kerosene and biomass with solar energy, the price of solar technology (such as lamps and cookits) is higher compared to the price people pay per week on kerosene and biomass. However, in a few weeks, the costs of 1 liter kerosene will transcend the costs of one solar lamp. By emphasizing the socio-economic costs of wood regarding serious health problems caused by smoke, and time and effort spent on collecting wood, the use of 'Solar tools' should be considered an important development in rural households.

It becomes obvious that the financial costs of the solar systems are high which entail a vast investment on the short run, whereas the benefits of solar systems can only be seen on the long run. Therefore, high initial costs make investment in solar systems a difficult first step to take in poor countries of Sub-Saharan Africa. However, when we target on the ongoing environmental and socio-economic constraints of that area, we have to seek for a sustainable solution. At the moment, it appears to be that 1.6 billion people still have no access to electricity. Therefore, the sun should be utilized in more effective way than simply being wasted shining on people's skin.

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Deliverable 3| Recommendations

In this research we have discovered the advantages solar power is able to bring in Sub-Saharan Africa and Uganda in particular. Simultaneously, we have discussed difficulties that could occur during and after implementing the technology. We have seen that solar energy is applicable for all kinds of applications and facilities which makes it a functional technology. Also, with a life-span of approximately 20 years, low maintenance costs and only the sun to rely on, solar technology is, on the overall, assumed to be reliable, especially in countries as Uganda that enjoy many sun hours per day. However, in order to make implementation feasible, substantial factors need to be taken into account. An important question remains:

what, in general, should be reflected upon when initiating projects regarding the implementation of solar energy in rural areas in Sub-Saharan Africa?

This research has processed a vast amount of data on solar technology. However, the subject still remains very general. Therefore, an overview of the main obstacles that solar energy entails will be provided in order to give short, but substantial answer on that main question. This will be proposed in the form of recommendations.

- **Solar energy may is not the only sustainable solution**

Apart from solar energy, other sustainable energy sources can be a solution for the energy shortage in Sub-Saharan Africa. Since this research focuses only on solar power, the possibilities of the other sustainable energy sources are not considered. However, they might have benefits over solar power, which implies that research needs to be done on the cost-benefit analysis of these sustainable energy sources, before making a decision to implement solar energy. Before deciding the geographical location of the area should be considered. An important environmental aspect is the weather condition in general (hours of sun per day, regular storms etc). Moreover, one should investigate the emergence of floods and earthquakes on a yearly basis of the region.

- **Take difficult conditions of a region into consideration while implementing solar technology**

To implement successful solar projects in Sub-Saharan Africa, its difficult conditions should be minimized. In this research, theft, corruption, lack of knowledge, and constraints on the (local) market have been acknowledged as being difficult conditions in rural Uganda. Even though these constraints are general, they may not be ignored for any region in Africa. In order to prevent theft and corruption, ownership by community is a way to ensure safety of the solar systems. Bringing people in a position of responsibility, they are likely to take more care of the technology once convinced of the solar advantages. In addition, knowledge regarding the technology of solar energy is inevitable for proper use of the technology. Therefore, much effort need to be invested in the training of the local people. This training should be done in cooperation with a recognized figure of a village that gains high status in African societies.

- **Explore the local market**

A constrained and weak developed market for solar energy advocates for low local investment. Whereas local investment is of high importance for the development and independence of Africa as a whole, solar energy is still too expensive for the poor African people. Although people are able to sell and buy solar technology (panels, batteries) on local markets, the quality and reliability is often not guaranteed since many 'second hand' products are sold 'first hand'. Commonly, the African local markets are known for providing low quality products. Unfortunately, since people are very poor, they seem to have no other option. Small loans (micro credits) could provide an important solution for this problem. An example in this context contains a woman that receives a panel for charging the batteries of cell phones. People would come to her hut, and in exchange for recharging their phones batteries, she takes in an amount of money. By providing these opportunities for the locals, the market can develop itself, instead of non-Africans (in order to provide 'help' for the poor) buying and importing the solar technology from abroad.

- **Make sure your project is able to generate progress and (local) independence**

This may be one of the most important aspects when implementing a (solar) project in Africa. Electricity is of high significance for the economy, and lack of access has been one of the main constraints for doing business in Africa. Close to 50% of African companies identify the lack of electricity as a major obstacle.[145] By simply imposing solar technology in rural off-grid areas without taking the long-term situation in consideration, the project is doomed to fail. In order to contribute to real development, people need to be able to benefit and develop themselves on the long term. Thus, development is not simply about placing a solar panel in a poor community, it is also taking into account the ability of a population to benefit from solar technology and the advantages it is able to bring on the long term. Therefore other initiatives should accompany the Solar project. For instance stimulating people to undertake economic activities since the provided Solar energy in homes will save a lot of time that was usually spend on collecting wood, water and fuel. Since more than 75% of the population in Sub-Saharan Africa does not have electricity (in rural areas it is more than 90%), it is assumed to be one of the most underdeveloped continent of the world.[146] Providing electricity to its population is therefore not a goal on itself, but a way to stimulate (small) business, progressing the level of education, and the status of women. Only when the implementation of solar energy stimulates people to work for their own future, the project can be labeled as a success.

- **Conducting field research**

In order to discover the constraints on the local market and the vision of life of African people it is important to do specific research in the field. When considering implementation solar technology, the needs of the individuals and communities can differ per region as can the technology required to fulfill these needs. Knowledge of the local situation is therefore of fundamental importance. Furthermore, while conducting research in the field, the possible difficult conditions of the location chosen for implementation of solar technologies should be determined and the financial costs of projects could be estimated. Therefore, for financial implementation of a project it has to be acknowledged, that for relative prosperous regions a micro credit would seem possible, while poorer regions would not have the possibility to pay the loans and sponsoring of a project would be more feasible. Only then a complete picture of the location and socio-economic characteristics can be made, which is needed in recital for implementation of solar energy.

While carrying out this research, the team was not able to undertake a fieldtrip to Uganda. However, we discovered that by contacting people in the field of solar energy, they were all happy to help and support our research by providing us with conducted projects, relevant data, and information on calculations. Logically, building up a group of contacts is necessary before going into the field. Especially in order to develop a good and reliable relationship with the local population, one should approach the head of tribes and the mayors of African villages. Faith and religion is of high importance in many African regions. When gaining a close relationship and trustworthy position in the African social structure, their cooperation and enthusiasm will highly contribute to the successful implementation of Solar technology.

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RESEARCH 3 | ONDERZOEK 3

CHINA AND INDIA

AS RESPONSIBLE STAKEHOULDERS IN TRADE POLICIES

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CHAPTER 1 |
Theoretical Framework

This chapter will shape the theoretical framework surrounding Responsible Stakeholdership (RS). The framework roughly consists of two main parts. The first part discusses the definition of RS from both a European and an Asian perspective. In other words, this research starts with formulating an answer to the question: 'to what extent is there a universal applicable and agreed upon definition of RS?' The second part will shortly explain the Hofstede-model, which will be used for the final analysis of the paper and its potential importance in studying RS.

I Perspectives on Responsible Stakeholdership

I.1 Responsible Stakeholdership in Western Perspective

The term 'Responsible Stakeholder' (RS) has been introduced in 2005 by then US Deputy Secretary of State Robert Zoellick (currently President of the World Bank).[1] Zoellick referred to the article "China's 'Peaceful Rise' to Great Power Status" by mr. Zheng Bijian, and posed the question how the US should deal with China's rising power. In his speech, Zoellick mentioned that 'all nations conduct diplomacy to promote their national interests. Responsible stakeholders go further: they recognize that the international system sustains their peaceful prosperity, so they work to sustain that system.' A responsible stakeholder would be more than just a member, it would work to sustain the international system that has enabled its success.

Zoellick emphasized that by introducing the term of Responsible Stakeholder, his intention was not to constitute a special category for China. Instead, he suggested that given China's success, its size and rising influence, it has an interest in working with other major countries to sustain and strengthen the international system that keeps the world more secure, enables it to be more prosperous, and creates opportunities for the peoples.[2] He added that this is a challenge for all the major participants: the European Union, Japan, India, Russia, others, and of course the United States, too.

International stakeholders contribute to defend or sustain the international system. Xenia Dormandy wrote that such an international system could be defined as a *norm-sharing mechanism* that establishes and enforces behavioral standards while sharing information to support those ends.[3] In this case, stakeholders are less focused on who brings what resources to the table and more on identifying and prioritizing geopolitical issues. Additionally, an international system could be a *burden-sharing mechanism* in which responsible stakeholders are willing to share responsibility and make sacrifices to achieve mutual goals.[4]

Likewise, Clemons and Konishi wrote that a responsible stakeholder is 'a nation with its own house in order, ready to contribute to the international common good above and beyond its own parochial national interests.'[5] Hence, an actor cannot be categorized as a responsible stakeholder if it remains confined to its own national interests.

More detailed, according to Zoellick, 'responsible stakeholders work to expand open and free trade, sustain a functioning international market, promote and spread human rights and democracy, stem proliferation of weapons of mass destruction (WMD), are open and transparent regarding military affairs, and attempt to resolve conflicts through peaceful means.'[6] One elaboration of the RS-concept has been written by Dan Blumenthal (Resident Fellow of the American Enterprise Institute). He formulated the expected behavior of a responsible stakeholder with regard to Zoellick's features:[7]

- Counter-proliferation: responsible stakeholders understand that certain regimes, aggressive, and linked to terrorist groups, are the greatest proliferation threats.

The great power should use all tools of statecraft to prevent those regimes in particular from obtaining weapons of mass destruction;

- Regional security: a secure, peaceful, prosperous and democratic system needs to be strengthened. In connection herewith, the principles of openness, ransparency, good governance, and the peaceful resolution of disputes come into play;
- Energy security: responsible stakeholders should rely upon the oil market and not mercantilism for their supply. They share a responsibility for the security of supply, which means contributing to the stability of supplier regions;
- Economic development and assistance, promotion of openness, lack of corruption, good governance, and furtherance of collective rather than purely national goods are all expected of a responsible stakeholder;
- Open and rules-based economy: responsible stakeholders work to open and liberalize new markets and abide by the rules of the international trading system;
- Peacekeeping and enforcement: for responsible stakeholders it can be necessary to intervene in unstable states to counteract possible terrorist threats. Peacekeepers and enforcers have to be nation builders as well and therefore sensitive to human rights;
- Human rights and state sponsored genocide: responsible stakeholders recognize that they have a moral imperative to stop genocide and civil war, and they realize that humanitarian disasters can destabilize key parts of the world.

Since many scientists have discussed the probable elements of RS, it would be unwise to depend on Blumenthal alone. After examining several treatises[8], one can conclude that the above 'requirement-list' is quite extensive and covers almost all issues, but one:

- The environment: in our opinion, environmental sustainability must be added due to its global impact and importance. Responsible stakeholders should behave to maintain the sustainability of the environment in their economic and trade activities.

It is interesting to see RS in the light of the academic debate in the field of International Relations between Realists/Neo-realists (Realism) and Liberal Institutionalists (Idealism).[9] Schiffer and Shorr wrote that 'given the context it was coined, the term was bound to be viewed as a demand placed by an established power on an emerging one.'[10] Originally, RS was brought up as strategy to 'manage' the rise of China and thus to encourage China to be a status quo power within a US-led international order. This is a clever advance from old-fashioned containment or appeasement strategies.[11] For realists/neo-realists, RS will be merely seen as a strategy in maintaining the status quo. This also confirms that RS is originally a term and framework developed by US as the hegemony of the current order.

On the other hand, Schiffer and Shorr then argue that 'there is nothing inherent in the concept that presumes a global hegemon or an immutable set of values.'[12] Adding to Dormandy's, Clemons' and Konishi's arguments, they believe that RS establishes the core principles of the liberal international order.[13] For liberal institutionalists such as Robert Keohane, RS is in line with multilateralism in terms of norm-sharing and the transcendence of national interests. Through multilateralism, states are perceived to be building accepted standards of behavior. These standards exert their own normative pressure on state action and contribute to the development of long-term obligations between states, which stress cooperation.[14] Thus, liberal institutionalists do not regard RS as a US-framework imposed on new rising powers, but it is a universal framework for all major participants. A European Council Statement on China-EU relations is one of the official papers expressing that RS is not merely a framework created by a dominant power, but it is based on universal understanding and cooperation.[15]

It is important to note from the above discussion that there is no disagreement between Western realists/neo-realists and liberal institutionalists concerning the concept and definition of RS. Rather, they disagree on why RS has been brought up in the first place, for what political reasons, and to whom this concept originally 'belongs'. Since the first explicit mentioning of RS occurred within US-forums and USChina relations, one can assume that the term is in principle an American concept. However, already in 1972, Francois Duchêne launched the question of the 'conception of the EU as a "civilian power" […] and its ability to expand its model of ensuring stability and security through economic and political rather than military means.'[16] The European Commission expresses in various statements their efforts 'to strengthen an effective, fair, just and rules-based multilateral international system, with the United Nations at its centre'.[17] In 2006, the Council launched the terms of 'international commitments and responsibilities', the need for an 'effective, fair, just, and rules-based multilateral system', and that the EU should actively support China's emergence as a successful and responsible member of the international community.'[18] If we translate the difference between the American and European perspective into the realism/idealismdebate, one can assume that the US can be found under the heading of Realism, whereas the EU is much more of an Idealist. Again, this does not mean that they disagree about the supposed content of RS, but it is important to be aware of this with respect to their intention, behavior, and emphasis.

Despite the lack of an exact definition, it is possible to distract the features of RS in Western perspective. Overall, a responsible stakeholder should *contribute* to the international order rather than merely benefit from it. Put differently, a stakeholder of the international community should take its responsibility through proactive and altruistic behavior on the global level. Besides, the definition of Clemons and Konishi should be taken into account: a nation can act responsible at the global level only when 'its own house [is] in order'.[19] National circumstances, for example concerning the environment,
human rights and the rules-based economy, should be in a comparable condition as those of the international order. Otherwise, a country is not likely to contribute to these standards on a larger scale.

Along the lines of these most important aspects of RS – *house in order* and *contribution to the international order* – this research will analyze Chinese and Indian trade politics by looking at its behavior towards both internal and external matters. With regard to trade politics, having your *house in order* means that the country in question has built itself in line with the norms of openness and market liberalization of the international economic order. Two internal aspects are relevant to a nation's *house in*
order: state capacity or effectiveness, and the private sector's entrepreneurial capacity.[20]

To evaluate entrepreneurial capacity, one should look at the conditions shaped by the state to create a flourishing private sector and attract Foreign Direct Investment (FDI). State capacity is concerned with how states have effectively built institutions capable of performing a number of economic functions in the market system, that affect efficiency and equity of objectives. This includes the function of creating an internal market by using the following objectives:

- protecting intellectual property rights (IPR);
- guaranteeing sanctity of contract and providing law and order;
- regulation and stabilization of domestic markets by ensuring a low inflation, macroeconomic stability, and avoidance of financial crises;
- legitimization of markets through mechanisms of social protection and insurance, and more importantly, through redistribution mechanisms and conflict management.[21]

As for its *contribution to the international order*, the analysis should focus on the country's behavior in the global economy, especially in its bilateral and multilateral trade relations. The eight RS-conditions, as mentioned before, are useful when analyzing the *contribution to the international order.* Whether the state concerned is trying to transform the rules of the international order, or whether it is trying to strengthen the current system, could be considered less important. What counts foremost is whether the state is willing and able to look beyond its borders.

I.2 Responsible Stakeholdership in Asian Perspective

Instead of using the term 'responsible stakeholdership', it is more common for Asian scholars and policymakers to use the term (global) leadership. In this respect, leadership means that a state should be able to come up with a vision that appeals not only to themselves, but also to the international community.[22] Kishore Mahbubani wrote that since Zoellick called on China to become a 'responsible stakeholder' in the international system, China has responded positively to this call. According to him, most Asian countries want to become responsible stakeholders in the international system. Mahbubani quotes prime minister of India, Manmohan Singh, who said in December 2006 the following:

'Just as the world accommodated the rejuvenation of Europe in the post-War world, it must now accommodate the rise of new Asian economies in the years that lie ahead. What this means is that we need global institutions and new global "rules of the game" that can facilitate the peaceful rise of new nations in Asia. It also means that existing global institutions and frameworks of cooperation must evolve and change to accommodate this new reality. This is as true for the reform and revitalization of the United Nations and the restructuring of the United Nations Security Council, as it is true for the management of the multilateral trading system, for the protection of the global environment or for the security of world energy supplies.'[23]

The above statements imply that in P.M. Singh's opinion, a *restructuring* of the current world order is necessary to accommodate the rise of Asian economies. *Fairness* is also emphasized by other Asian leaders. Chinese analysts and policymakers believe that economic globalization created the open economic system, which has been essential for China's growth. Although pressuring China to live up to international commitments, the globalized world also offers opportunities to express its discontent, to take measures to defend its economic interests, and even to assert a leading role in global governance. Shi Guangsheng

(China's former Trade Minister) stated that the WTO has failed to reflect the interests and demands of developing countries in a more adequate fashion.[24] Restructuring the current world order to
become more fair and just is an important aspect of being a responsible stakeholder.

On the other hand, Indian scientists put less stress on the notion of restructuring the current world order. Responsible nations do not necessarily agree with the international system, but they are willing to talk about it.[25] Consequently, they participate in international forums, for instance in the UN or in other financial, regional, and bilateral settings. An RS makes a positive and qualitative contribution to the current international system. Even small contributions are enough to be called RS on that issue. The less developed a country is, the more domestic dependencies it has. When internal matters become urgent, contribution on the international level is not possible in that particular field.[26]

Importantly, Asian countries emphasize the state sovereignty, national self-determination, autonomy, and pragmatism as the virtues of being a global leader or responsible stakeholder. The mutual benefit for 'self' and 'others' is the main consideration, in contrary to normative and ideological assumptions.[27] This may explain the current policy practice of India and China in joining the multilateral framework, which serves their own interests on the one hand, but serves wider interests on the other.

Being pragmatic also means to prefer mutual and fair economic gains above normative issues such as human rights and democracy; to limit peaceful resolution and common security by the principle of non intervention;[28] and to put environmental and energy sustainability considerations on the agenda, while emphasizing the internal needs and capabilities. Remembering our earlier realism/idealism-discussion, one can identify clear realist aspirations here. However, this sovereign Asian approach does not necessarily weaken their perspective on RS. There is nothing wrong with trying to defend domestic trade interests. In fact, one could argue that defending your self-interest is responsible state behavior, taken into consideration the responsibility to protect and develop your own population. However, it should be remembered that what is meant by domestic interests does not always mean that those are really in the best interest of the country because, as a consequence of domestic interplay, the 'domestic interests' are actually representing the interests of a certain domestic group or elite.[29] The notion of domestic interest is also expressed in the concept of China's 'Peaceful Rise'. The Peaceful Rise is a phrase that has been used by officials and scholars in China to describe the country's foreign policy approach in the early

21st century. It seeks to characterize China as a responsible world leader; emphasizes soft power; and vows that China is committed to its internal issues and improving the welfare of its own people before interfering with world affairs. The term suggests that China seeks to avoid unnecessary international confrontation.[30]

Furthermore, in an article on the emerging and increasing importance of East-Asian countries, Jusuf Wanandi builds upon the RS-concept in connection with the Asian role in global governance. The author explicitly mentions the influence of Zoellick's definition by saying that 'an important recent development has been the establishment of certain principles in the relations between the United States and China that originated with the suggestion by then Deputy Secretary of State Robert Zoellick to recognize Chinese stakeholdership in the global and international order and in its institutions.[31]

Subsequently, Wanandi states that 'this new approach has started to work, especially on the North Korean nuclear proliferation issue. This principle will work if China takes its responsibilities seriously and if the United States accepts some temporary exceptions that can be agreed upon through dialogue.'[32] Furthermore, Ralph Cossa confirmed that the RS-concept may have been regarded with suspicion in Asia in the beginning, but now it has become mutually accepted to a certain extent. The exact content is still open for debate, but roughly, the idea of international problems, mutual interests, and joint responsibilities is also well-known in Asia.

All of the elements coming up when Wanandi emphasizes the essential elements of East Asia's future responsible stakeholdership, resemble its Western counterpart: non-proliferation; the success of the Doha Development Agenda; greater support and cooperation on matters of the global good, such as climate change; energy security and availability; efforts on pandemic diseases; human security issues, such as international crime, trafficking, and money laundering; measures against regional and global terrorism; and support for the reforms within the UN-framework.[33] Before concluding this section, another important feature of the Asian perspective on RS must be pointed out: rule-by-example. Whereas the EU strongly emphasizes and stimulates rule-by-law, the Asians put more emphasis on the example set by leaders. Put differently, this means that other major powers' behavior, good or bad, will have an important impact on China's thinking and behavior. It is therefore crucial that the EU sets a good example in taking its international responsibilities, and stimulates the US to do so too.[34]

In order to make a useful comparison between the Asian and Western perspective on RS, we will use the eight elements as mentioned in chapter I.1. A concise analysis of Chinese and Indian views on these elements will illustrate the Asian perspective on RS. For the benefit of this research it is not necessary to go too much into detail on the different features, because only final conclusions of Asian behavior help us determining whether the Western view has been adopted by China and India.

First, on the account of counter-proliferation, China and India disagree with each other. China seems to collide with the Western non-proliferation standards, seeing their support for complete elimination of nuclear weapons.[35] On the other hand we can see that China demonstrates passive behavior when it comes to stimulating international disarmament and, for example, stimulating Iran and North- Korea to eliminate their nuclear arsenal. As for India, it proclaims itself as a nuclear weapon power and demands the accompanying international status and rank. It even pleads for rule changes to allow it to receive extensive imports of nuclear fuel and reactors. Indian politicians and atomic scientists reject outright any proposal that might limit India's self-sufficiency in this area.[36]

Secondly, with regard to the regional security, Asia also recognizes the indispensable need to cooperate transnationally to counteract international security threats: 'only by strengthening international cooperation can we effectively deal with the security challenge worldwide and realize universal and sustained security.'[37] China's engagement in and with institutions like ASEAN, ASEAN+3, ASEAN Regional Forum, APEC, Shanghai Cooperation Organization, East Asia Summit, and the Six-Party Talks demonstrates its willingness to build a stable, secure and prosperous region. The future Chinese attitude towards other Asian great powers (e.g. Japan, India) will indicate whether they have learned what it means to be a responsible stakeholder. On the other hand, it can be argued that China is still involved in many territorial disputes with its neighbors (e.g. Taiwan, Vietnam, Philippines, India, Russia). Balancing those two developments, we could say that the Chinese perspective on regional security is characterized by an increasing awareness of its importance, respect of other states' sovereignty, and non-interference in internal affairs.[38] Moreover, China also confirms the emergence of international security threats: the latest White Paper on National Defense specifically refers to the 'diversifying and globalizing' security threats.[39]

Thirdly, concerning energy security, both India and China – as well as other developing countries – need immense amounts of energy to provide for its internal economic development. That said, all their perspectives on energy security stand in the light of this core value. Therefore, they have to safeguard today's and tomorrow's needed energy resources. Nevertheless, their records on energy security do not reach beyond extraction to safeguard the security of supplier regions. Again, this is due to the principle of non-interference in another state's internal affairs. In their view, energy security consists merely of the availability of sufficient supplies at affordable prices. In a recent contribution by China's National Energy Administration, the Chinese priority for economic expansion and thus increased energy production/consumption is expressed. Only at the bottom of the list, one can find renewable energy.[40]

Fourthly, for the sake of economic development and assistance, the principle of pragmatism comes first and foremost in Asia. In other words, 'it does not matter whether a cat is black or white; if it catches mice, it is a good cat' (Deng Xiaoping).[41] China's engagement in Africa testifies to their pursuit of national interests, but also their preference for mutual gains. In other words, it is convinced of the possibility of a win-win situation. Besides loans and grants, China delivers assistance in the form of education and training. The China-Africa cooperation glooms hopeful and could carefully be considered as a confirmation of its responsible behavior. As said before, China's realistic approach prescribes that there must be something in it for themselves, but still, their efforts transcend national interests.

Aside from its role in the tsunami response group and in UN peacekeeping missions, the Indian government has been less enthusiastic about participating in burden-sharing mechanisms.[42] The nation is not yet willing to forgo immediate domestic interests for longer-term international objectives. Dormandy argues that India's domestic political dialogue still revolves around the primacy of its sovereignty and the promotion of national, instead of international, goals. With 25% of its population living in poverty, India is also constrained by political and practical necessity to focus on reducing rural poverty.

Fifthly, in connection with open and rules-based economy, both Asian countries entered multilateral trade negotiations, such as the WTO-rounds. However, whereas China seems to have succeeded in adapting its economy into some sort of free market socialism and is actively thinking about shaping a new International Political and Economic Order,[43] India still holds on to high tariffs for reasons of their population's welfare. Naturally, this is 'understandable', but it leads us to think that India's view on open and rules-based economy lacks the identity of a responsible stakeholder according to western standards. C. Raja Mohan states that the current approach is clearly unsustainable and therefore the balance in India seems to be shifting.[44] While the population continues growing at a rate of 15 million people every year and land availability decreases, India has to find a solution to produce more in agriculture to feed its people and maintain its self-sufficiency. Therefore, India will be facing a serious food security problem, unless it opens up its agricultural policy.[45] This suggests that the Indians in principle agree with the need for an open and rules-based economy, but that protectionist motives come first for now.

Sixthly, with regard to peacekeeping and enforcement, Asia keeps it head lower than the US or the EU. The principles of non-interference and state sovereignty prove their value again in this respect. Nevertheless, 'Beijing demonstrates a willingness to take some risk and accept some cost that benefits more than only its own narrow self-interest'.[46] India is also a major contributor to UN peacekeeping troops. Sometimes they are blamed for acting only slightly and ad hoc, but their insistence on noninterference makes them a reluctant peacemaker. Nowadays, the non-interference principle collides with the emerging 'responsibility to protect'.[47] This testifies to the increasing Asian agreement with peacekeeping-necessities.

Seventhly, regarding human rights, the Indian Constitution stands as one of the most comprehensive and self-contained documents on human rights. India took active part in drafting the Universal Declaration on Human Rights, especially highlighting the need for gender equality, and is fully committed to the rights proclaimed in the Universal Declaration. India is also a signatory to the six core human rights covenants and the two Optional Protocols to the Convention of the Rights of the Child.[48] It should be noted that, in practice, the implementation might not yet be in accordance to what is being stated in the official papers. Based on the Summary of Stakeholders' Information in India's Universal Periodic Review, India is still lacking to tackle various aspects of human rights in the country.[49] For example, women's rights within family and marriage (especially rights to properties, inheritance, and maintenance) are not ensured. The number of child marriages are rampant: 24% of the 15-19 age group is married.[50] Additionally, despite the existence of laws protecting human rights, India has failed to properly implement and enforce policies to protect its marginalized communities, such as the Dalits, tribal groups, religious minorities, women and children.[51]

As for China, the government publishes many reports, white papers, and official views on human rights issues. The fact that they do discuss these matters points to their concerns. In a joint statement with the EU, 'the two sides emphasized their commitment to the promotion and protection of human rights, the rule of law, and the strengthening of dialogue and cooperation in the field of human rights on the basis of equality and mutual respect.'[52] Clearly, their perspective on human rights resembles the Western perspective, but how they live up to their commitments, remains an open question for Chapter 2.

Finally, concerning the sustainable environmental issue, developing countries such as India, China, and many other Asian countries, stress the mutual but differentiated responsibility. In other words, economies that are still 'under construction' also have the duty to take environmental consequences into account, but the industrialized countries need to carry a heavier burden since their shoulders are stronger. The Chinese government has formulated and implemented a National Climate Change Programme. Additionally, China is member of the Kyoto Protocol and United Nations Framework Convention on Climate Change (UNFCCC). Despite this obvious international willingness to cooperate, many researchers are skeptical: China's economic prosperity will always have priority. This can clearly be illustrated by the latest Climate Conference in Copenhagen where China wrecked an international agreement. China refused to allow any binding target to cope with climate change. China, backed by India, has suggested to remove the target to restrain the temperature rise to 2o C in 2020 and use the language of "as soon as possible". It seemed that in Copenhagen, China wanted to weaken the climate regulation regime in order to avoid the risk that it might be called on to be more ambitious in a few years in time.[53] India's perspective on climate change and reduction of CO2-emissions can be considered very pragmatic. Rajani Ranjan Rasmi of the Ministry of Environment and Forests stated the following in an official letter towards the United Nations Framework Convention on Climate Change (UNFCCC): 'India will endeavor to reduce the emissions intensity of its GDP by 20-25% by 2020 in comparison to the level in 2005 […] the proposed domestic actions are voluntary in nature and will not have a legally binding character.'[54]

As we can see, all these aspects show us the same line of Asian reasoning, which leads to a somewhat different approach to the concept of RS. In theory, the countries agree to a great extent with the Western perspective. However, if the principles clash with internal economic development, noninterference, and state sovereignty, the balance often tends to favor their national interests above international public goods.

II Hofstede-model

To come to a solid conclusion by the end of this research, it is necessary to create some sort of hierarchy in interests and values for each actor. By doing so, it will be possible to formulate recommendations on which aspects China and India can, and on which they cannot be pushed. Along these lines, it would be valuable to use the Hofstede-model, as developed in cross-cultural disciplines, such as intercultural communication and international business. This model prescribes which norms and values are of vital interest to actors and which are of least importance. By comparing differences, foreign policy can be made in a more efficient way, as to target those lower values and working inwards to tackle those values that are less changeable. In connection with the liberalization of markets, this would signify a priority for overcoming the values (problems) with the lowest resistance. The highest values in the hierarchy are known as the *core value*s. By understanding cultural differences we are able to predict whether or not someone or something will integrate into a system.[55]

Hofstede Model on Cross-Cultural Value Analysis

Following the line of reasoning as we can find in theories on political socialization, this model is applicable for RS as well. By appraising differences in values for China and India, it will become clear to what extent they are willing to trade in old practices for responsible behavior in the world system, and to what extent they will *integrate* into the concept of RS. Every value that is not a core value is considered to be exchangeable to a certain extent. Naturally, the lowest values are the first to be sacrificed. This model could provide us a convenient step-by-step-approach, which guides Dutch, European, or Western trade policies in general, towards a common RS-understanding with China and India.

III Conclusion

By comparing the Western notion of Responsible Stakeholdership with the Asian idea of Global Leadership, it can be concluded that there are some common values between the Western and Asian perspectives: an RS should *contribute to the international order* instead of merely benefit from it. An RS should not only pursue its own interests, but should transcend its borders by pursuing wider or global interests. Before doing so, an RS has its *own house, at least partly, in order.*

China and India seem to follow up Western ideas in official meetings, legislation and international covenants. However, if the principles clash with internal economic development, noninterference, and state sovereignty, the balance often tends to favor their national interests above international public goods.

On the other hand, there are differences in perceiving the current order. As Asians see it, the current order is not yet fair and supportive to developing countries, and likewise, emphasize the importance of restructuring the current order. There is also a different emphasis on the values needed to become an RS, such as pragmatism and autonomy.

In the next chapter we will focus on the Chinese and Indian trade policies and their trade relations with the EU in the light of the above RS definition. It will revolve around the following question: to what extent do China and India behave as Responsible Stakeholders in the area of trade policy?

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