Feasibility study for solar street lamps in Kayunga, Uganda

Final Report on the 18. November 2019 – Part 1 (without Appendix)

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Abstract

The following study is the final report for the project ‘feasibility study for solar street lamps in Kayunga, Uganda’. The project took place from April 2019 until November 2019 in Witzenhausen, Germany and Kayunga, Uganda. It was written by two electricians from Uganda and two students from Germany during this time period.

In the beginning in chapter 1 the background of the study is explained, the study-team is introduced and basic information about Germany and Uganda is given. In chapter 2 the technical knowledge is shown and two different types of systems are introduced. Also simulations for one of them can be found here. Chapter 3 introduces the geographical intricacies of Kayunga and Bukolooto and shows where and how many lamps are planned. In chapter 4 the importance of recycling is explained and some hints for maintenance are given. The team in Kayunga also visited two other projects in Uganda, the results of these visits are described in chapter 5. Also the visit to solar companies in Uganda was part of the stay there, offers and results of these visits can be found in chapter 6. With the company´s offers and some other background information a rough cost estimation was calculated. An overview of the results is written in chapter 7. To get the necessary funding for this project some research about funding projects was done. All projects can be found in chapter 8. The last part of the study is a closer look to the possible risks, which can be found in chapter 9. In the end a conclusion is given in chapter 10 and recommendations for the future are explained.

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Introduction

1.1 The ASA-project and the team

Solar street lamps in a small city in Uganda is for sure an interesting and ambitious project., and for a developing country very difficult to conduct. Therefore it makes sense to start with a feasibility study. This study was only possible with the background of the two twinning towns of Kayunga (Uganda)and Witzenhausen.(Germany). This relationship will be explained and described within this introduction.

The two cities of Witzenhausen and Kayunga are twinning towns since the year 2001. The partnership is kept alive with regular visits in both countries and different projects.
In Kayunga the main stakeholder are the Kayunga Town Council (KTC) and the NGO 'Kayunga Community Development Association' (KCDA). Witzenhausen has a twinning town association that takes care of the partnerships with all twinning towns in Italy, France, the UK and Uganda. The association of 'Uganda-Team Witzenhausen e.V. is active in the partnership with Kayunga since 1993 and has also a place in the twinning town association. Additionally the One-World-Shop Witzenhausen build up a partnership with the vocational school 'Mirembe Technical School' (MTS) in Kayunga. In 2017 Uganda-Team invited a group from Kayunga to Witzenhausen for an exchange program. Within this visit, a discussion started about the risks of dark roads in Kayunga and the idea to install solar street lights in the city. After a longer exchange time between Uganda-Team and the cities of Kayunga and Witzenhausen, the project was started to develop a feasibility study about this project.

'Engagement Global gGmbH' supported this study. This is a German corporation, that supports developing initiatives with different services. Engagement Global combines different activities of the ministry of economic cooperation and development (BMZ) to support civil and communal activities in the education of international development.

Together the Uganda-Team, the city of Witzenhausen and its office of coordination for municipal development politics applied for support by Engagement Global for their program 'ASA-Kommunal'. The application was for the version 'global!, because it was important to do the project on one level and give the possibility to travel to the partner country to both sides.

The ASA-municipal project ‘global’ included two parts:

- Phase I: A three-months stay in Germany, Witzenhausen for preparation and orientation from April to June 2019
- Phase II: A three-month stay in Uganda, Kayunga for elaboration and implementation from July to October 2019

In both phases two participants from Uganda and two from Germany where involved:

- Rodney Kibwika (Kayunga, Uganda) - electrician in Kayunga
- Rajab Kasujja (Kayunga, Uganda) - electrician in Kayunga
- Sophie Scheller (Germering, Germany) - Student renewable energies
- Yannik Woll (Saarbrücken, Germany) - Student renewable energies

The German participants were selected after a national announcement by ASA with support by the Uganda-team and the city of Witzenhausen. The Ugandan participants where chosen by Kayunga Town Council.

The following topics where part of the project phase in Germany:

- Team building
- Training in technical skills and internships
- Training in the basics of project management and study writing
- Exchange of information and visions between Kayunga and Witzenhausen
- Developing of a network
- Planning of phase II in Uganda
- Preparation for life in Kayunga (Culture, health, habits etc.)

During the second phase, which took place from the end of July until the end of October, focus was on the local conditions in Kayunga. Research was the done in Kayunga and other municipalities with similar projects to learn from their experience.

Apart from the technical contents also life in Germany and Uganda and the differences in culture where important for the project.

The cooperation within the team developed the interest in renewable energies not only in Kayunga but also in Witzenhausen. Especially the different backgrounds of the participants and their individual knowledge influenced this process. The network for cooperation in development politics was increased. The population of Witzenhausen got new ideas about the use of renewable energies in an international context and especially for the use in Africa. This project is therefore an impulse for sustainable development in both municipalities.

Additionally the intercultural encounter was an enrichment for all sides. It lead not only to personal contact and friendship, but opened also the view for different ideas and ways of working on both sides. All these factors increased the town twinning connection between the two municipalities of Witzenhausen and Kayunga and enriched it with new perspectives.

On this point we want to say thank you to all the people, who supported this project and made it possible. We want to name the following persons especially:

- WOLFGANG GEISENBERGER: director of the company PVcare in Witzenhausen, who was responsible for the technical education of the participants and answered all project based questions.
- KOLJA BRAUN: Responsible for questions about development politics of Witzenhausen, who coordinated the communication with ASA
- MARGARET NANSUBUGA (Town Clerk Kayunga) and RHAMULA NABATTE, who organized and supported the project in Kayunga.
- ISABELLA JUNKER: Chair person of Uganda-Team, who supported the project with her knowledge about Kayunga the contact between the members in Kayunga and Germany.
- DIRK JUNKER: project manager of Uganda-Team, who organized the whole project
- PETER OESTERLIN organizational support of the project and advises in all situations

The ASA-Team

Picture 1.1 shows the ASA-Team and we want to introduce us as the authors of this study.

My name is SOPHIE SCHELLER, I´m 24 years old and I come from a city close to Munich. I did my Bachelor degree in renewable energies and finished a few months before the project started. I wrote my Bachelor thesis with ‘Engineers Without Borders´ about a water power project in Cameroon and that was my first touch with international projects in Africa. I wanted to deepen this experience before I started my master courses in sustainable management - water and energy. So I applied for this project and was very happy to finally travel to Witzenhausen in April this year and to meet my team. The experience of starting a project like this for 6 months without daily supervision and an international team was quite intense especially during the first weeks. Especially language problems made the first days a challenge for all of us. Also different experiences and habits where challenging during the whole time, as we had to discuss almost every step in our daily work. But this also brought up many aspects a less international team never would have thought of, so we as a team and our study learned a lot from this constellation

Especially the second part of the project was challenging for me as I could not join the team in Kayunga and had to stay at home. So communication had to be done via Internet (talking or texting) and some information got lost on this way or had to be discussed more often than without this handicap. But in the end I think we all learned from this situation and made the best out of it. Especially research topics like the funding chapter and the simulations where easier to be done in Germany, so it also had some advantages.

So finally I´m really glad I had the opportunity to work in this project. It was not always easy but I learned a lot about myself, about working in an international team and of course about the challenges of solar street lamps.

My name is RAJAB KASUJJA and l am a 22 years old Ugandan (Kayunga town council). I did a two year course (2017_2018) and I got my certificate in Electrical installation systems and maintenance last year in November. I had internships in different parts of Uganda with several companies for example Arab contractors.

I joined the ASA program in Germany (Witzenhausen) for three months for the feasibility study of solar street lamps project at the beginning of this year (April) up to the end of June where I worked with a team of three participants, two Germans and one from my country.

I enjoyed working with new (international) people from a foreign country, because they were friendly and kind though at the beginning it was quite rough because of the language (difference in accent). This helped me acquire experience and learning more about other cultures.

And we also had a second phase in Kayunga (Uganda) for the other three months, and communication was sometime affecting the project since one of our team remained in Germany because of her confidential issues.

I liked the project because I am very attached to it since am also a born of Kayunga.

My name is KIBWIKA RODNEY, I’m 30 years old and I come from a town called Kayunga in Uganda. I did my craft part 2 in electrical installation at St Joseph’s technical institute Kisubi from 2006 up to 2008. From then I have been working as an electrician for domestic and industrial wiring. So I applied for the feasibility study for solar street lamps Project and I was very happy to travel to Germany in April 2019 and to meet new friends , I learnt a lot like about cultural differences, renewable energy and solar systems within the last six months, the weather changes in Germany was challenging.

I´m YANNIK WOLL, a 26 years old student, originally coming from Saarbrücken. I study renewable energies at the University of Kassel on master level. Before finishing my degree, I wanted to get some practical experience connected to my field of study, in a new international context to widen my view and to extend my knowledge. Since I´ve never been to East Africa, this was the perfect opportunity for me and I´m grateful, that I had the chance to participate in this project. In conclusion it was a really interesting and valuable time to me, since I had the chance to meet so many new people, had to accomplish difficult situations and was able to experience a so far unknown culture.

Figure 1.1: ASA-Team (from left to right Sophie Scheller, Yannik Woll, Rajab Kasujja, Rodney Kibwika)(Source: Daria Neu/HNA)

1.2 Project goals

The aim of this project is for now writing a feasibility study for solar street lamps in Kayunga. The final vision is to see Kayunga shining by night. therefore different tasks and topics are important.

First, the actual local conditions need to be checked. This includes to double check the plans and expectations of Kayunga Town Council in chapter 1.5, as it is the head of the project. This has already been done by several emails and is a process to be kept on during the whole project. Also the locations for the lamps and a priority list for the different streets belong to the requirements from Kayunga town council and are described in chapter 3. Another part of the local conditions is the weather and the climate in Kayunga as these aspects have a high influence on the needed components such as PV-panels and batteries, as described in chapter 1.4.Another point concerning the local conditions is the introduction to the community and the communication with them. The lamps are going to be set up to serve the public, that for it is really important to include them into the process. When it comes finally to the process of setting up the lamps the availability of local labor must be checked.

Apart from the local conditions a big part of the study is about the technical basis of the lamps. By now there are two different concepts that need to be compared. On one side there is the possibility of building up a centralized system. This requires one central spot with the PV-Modules and battery. The lamps are then connected with cables in air or earth to this central spot. It makes sense to build up more of these centralized systems in the different parts of the city. On the other hand, it is also possible to install a decentralized system. In this system every lamp has its own PV-panels and a battery and is independent from the other lamps. Both systems with their advantages and disadvantages shall be discussed in the study in chapter2.

To compare the two systems, a market research is necessary to have the possibility to compare costs and systems. Additionally, other projects must be found to get valuable information about problems in their projects. For the components it is important to get a supplier in Uganda, to make sure, that there is somebody to get in touch with in the case of a failure of the components. Also, the research on other projects is best to be done in Uganda, as they faced the same conditions as this project is facing now and in future. All these issues will be described in chapter 5

Every project contains a number of risks, an overview over the possible risks for the installation of the lamps is given in chapter 9.

Another part of the study is the financial part. On one hand a financial plan has to be set up which includes the most important parts of the final installation but also the maintenance in future and the replacement of broken parts, closer information can be found in chapter 7. On the other hand, a research on possibilities for funding has to be done. To install lamps is not goal of this project and needs to be done within another project. But as Kayunga Town Council cannot afford the lamps by itself a possibility for an external funding by some organisation has to be found. Companies and organizations for funding are described in chapter 8.

1.3 Why are lamps needed

Until now Kayunga has only a very small number of street lamps run by the public grid supplied with a hydro power. Only a small number is installed in the center of Kayunga, so the rest of the city is still dark. Additionally the electricity costs are relatively high and blackout is more than a rare problem. So even if grid based lamps are installed, the running costs will be quite high and there is, because of the blackouts, no guarantee, that they will run the whole night. So the idea came up to install a reliable and sustainable street lamp system to avoid complete darkness at night, what often leads to robbery or crimes. The best solution for such a system is solar street lamps.

1.4 Comparing Germany and Uganda

Kayunga and Witzenhausen are twinning towns. To appreciate this special relation between these two cities the situation between Germany and Uganda shall be described with in this chapter. The focus lies therefor on climatic differences, but also on differences in electricity and geography. Uganda has about 40 Million inhabitants, while Germany has about 82 Million inhabitants, so double the number. This is important to know to understand some of the data presented.

Table 1.1 shows the differences in energy production and energy consumption. The electrification rate in Germany is by 100 %, so everybody in this country has access to electricity. In Uganda this rate is by around 22 %, this is also a reason to install the lamps independent from the grid, to make them more reliable. Also the huge difference in electricity costs is a reason, why the number of the old already existing lamps should be reduced in futuure, and it is more sufficient to build up a new system without the local electricity grid.

Uganda has, compared to Germany, a high amount of renewable energies, but most of it comes from big hydro power plants build from Chinese companies, what leads to the high electricity costs. The low CO2-Emssions come from the low electricity assumption, also because of the low electrification rate, the high amount of hydro power and also because of the lower population in Uganda. This shows the CO2-Emission per person. In Germany this emission is by 10 t/person, in Uganda this rate is by 0,11 t per Person.

	Germany	Uganda
electrification	100 %	22 %
electricity production	612 billion kWh	3,4 billion kWh
electricity consumption	536,5 billion kWh	3,1 billion kWh
electricity export	78,8 billion kWh	121 billion kWh
electricity import	28,3 billion kWh	50 million kWh
installed generation power	208,5 million kW	1.02 million kW
fossil fuels	41%	19 %
nuclear	5 %	0 %
hydro	2 %	68 %
other renewables	52 %	12 %
electricity costs	28 ct/kWh	~22 ct/kWh
CO2 Emissions	847,6 Mio t	4,7 Mio t

Table 1.1: Differences in electricity systems

Another interesting part to look at for the installation are the different climatic conditions and the geography. First of all, its obvious that Uganda is much higher above sea level than Germany. The maximum temperatures are quite similar, but even the lowest temperature in Uganda is with 0 °C much higher than in Germany (Especially as this temperature was measured on Ugandas highest mountain is not valid for the rest of the country). This is important for the batteries, as they must not face temperatures under 0 °C in some point and can therefor be installed outside. Also the power of the PV-Modules decreases with rising temperatures, as described in chapter 2.1.1. Also the average temperature is interesting for this purpose, as it is much higher in Uganda than in Germany, This leads to a higher stress for both modules and batteries. And also the charge controller needs an extra ventilation or cooling with increasing temperatures.

The number of sun hours a day and the radiation have a high impact on the sizes of components like the modules and the battery. Especially the lowest radiation of about 130 kWh/m² influences these values.

The rainfall may also influence the power of the modules. Especially in Kayunga the roads are quite dusty, so the modules get dirty fast. Rainfalls can clean the modules again from time to time and therefore increase their power. On the other hand is the radiation on rainy days lower, than on sunny days. Only a simulation and future tests can show which effect is higher.

The wind speed affects especially the construction of the modules. If it has to face higher wind speeds the construction of the PV-Modules needs to face them and has to be more stable, But as the average wind speed is quite low, the stability should not be a problem.

	Germany	Uganda
total area	357 022 km2	241 038 km2
lowest point	-3,5 m	614 m
highest point	2963 m	5110 m
max. recorded temperature	36,7°C* [dwd19]	38 °C** [wat19]
min. recorded temperature	-22 °C* [dwd19]	0 °C** [wat19]
average temperature/day	10 °C	21 °C
average. sun hours/day	4,8 h	6,58 h
average solar radiation	1181 kWh/m2	1182 kWh/m2
absolute rainfall per year	676,6 mm/m2	1356 mm/m2
average wind speed	3,5 m/s	2,3 m/s

Table 1.2: Climatic and geographic differences (*Kassel, **Kampala

All these differences have influence on the project and therefore have to be kept in mind and need to be calculated during planning, installation and maintenance. [cia19]

1.5 Circumstances in Kayunga

1.5.1 Conditions of the Project

The conditions for the street lamp project are quite complex and include a number of different aspects.

First, the weather and climatic conditions need to be evaluated. As Kayunga is close to the equator, the temperatures are high during the whole year. So especially the batteries have to deal with these high temperatures, but also the PV-panels need a higher power to compensate temperature losses. The vicinity to the equator also means a stable time for dawn and sunset, so the nights and the times during which the lamps are needed are stable through the whole year. Uganda has two rain seasons a year during in which the radiation is lower than during the dry seasons. For these reasons the capacity of the PV-Modules and the batteries need to be calculated for this lower radiation. Another important issue for this project is safety. The whole system needs to be secured against extreme weather conditions like strong wind or rain, so that nothing and nobody is damaged. Even though the average wind speed is quite low. stronger winds can occur and damage the lamps.

Another problem for the installed lamps is the dust on the roads and in the air. Due to this dust the PV-Modules get dirty quite fast and a lot of power is lost. For that reason a regular cleaning is needed to ensure that there is enough power for the lamps to shine the whole night.

Also theft is a huge problem. In a centralized system the PV-panels and the batteries need to be stored in a place that only authorized people can access. Batteries can be stored in a room in the Kayunga Town Council office building and the panels need to be installed on a roof which is not too easy to enter. If a decentralized system is set up, all parts of the lamp must be located on top of the pole which makes it harder to maintain them but also harder to steal. Apart from this some requirements were defined by Kayunga Town Council itself. For example, the location of the lamps and their priority of installation is set up by them. Here a map from Kayunga Town Council is given, which shows the spots and the streets, which are going to be illuminated.
Also, the distance between the lamps is more or less fixed to 30 m by Kayunga Town Council but also depends on the power of the chosen lamps.

Another important issue is the funding of the lamp. Kayunga provides a fixed amount of money a year for installation and maintenance. Apart from this the number of installed lamps depends on the range of funding that can be collected. All these circumstances have to be considered during this project for the study and the installation later on.

1.5.2 Requirements from Kayunga Town Council

Kayunga Town Council has some requirements for this project. One big issue is the location for the lamps and the priorities for the different places and streets, which will be explained in chapter 3.

The budget for this project has already been planned by KTC, for the first year 3700 € are planned to get started. This amount should be increased every year. Due to this aspect Kayunga Town Council expects low costs for a still good quality for the system. They also plan to increase the awareness of the community in Kayunga. This process already started with extensive announcements in the closer past. Most people are already excited about the project and want to get rid of the darkness in the streets.

Also the communication between the twining towns is very important to Kayunga Town Council due to learning about maintenance, repairing and servicing.

2 How does it work - technical description

The main part of this study will be the technical description of the possible systems. To gain a better understanding of the challenges for solar lamps in Uganda also a short introduction in the important aspects of solar technologies will be given here, Afterwards the different systems have to be simulated to get a better understanding. In the end the different systems are going to be compared to show each advantages and disadvantages.

2.1 Description of the system and its components

Every PV-System contains different components, as can be seen in Picture 2.1. All these components, the module, the charge controller, the battery, the inverter and the load, in this case the lamps, are described in the following.

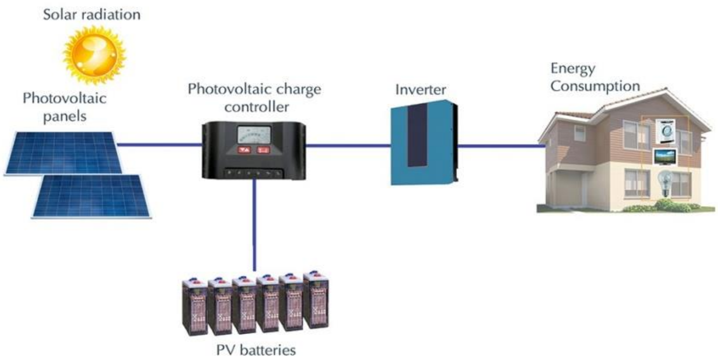

Figure 2.1: Scheme of a basic PV-System with all important components [Sch19]

2.1.1 PV-Modules

The first part for every solar system, no matter what it is used for, are the PV-Modules. Three main technologies are important these days. First mono crystalline panels can be used. They are the most efficient ones by now, but also more expensive, than poly crystalline modules. These are the panels which are mostly used and are also in the focus for this study. A third technology is thin film modules. But as the efficiency is much lower, and therefore more space is needed, this technology will not be used in this study. Also the prices for small plants are much higher, than poly crystalline panels. Thin film modules are therefore only common in bigger power plants with a higher power.

There are some aspects that have a high influence on the power of a solar module. First to mention is shadowing. Even a small part of the module which is under shadow could decrease the power in a high rate and should be avoided. Shadowing could come from high trees or houses in the area, but also from the dust in the air. It is therefore essential to clean the modules, when they get too dirty, to keep the needed power of the modules.

Not only shadowing, but also the temperature has a high influence on the power of a PV-Module. The power is declared under Standard test conditions (STC), which means a temperature of 25 °C, a radiation of 1000 W/m2 and an air mass factor of 1,5. These conditions are usually not reached under normal conditions. Especially the temperature is much higher with this radiation. But a higher temperature decreases the power of the modules, so a natural ventilation should be ensured underneath the modules. [DGS13]

The lifetime of a usual PV-Module can be calculated with 20-25 years. Closer details can be given from the supplier.

2.1.2 Charge Controller

To protect the battery from over- and undercharging, and a backwards flow from the battery into the module, a charge controller is essential. Usually this system measures the voltage on the battery. If the difference to the usual voltage is too high, the load or the module gets disconnected from the battery. For the basis controller two different technologies are possible, more common is the Shunt-controller, but a serial controller is also possible. Both have different advantages and disadvantages which are not part of this study.

Apart from protecting the system, another task for the controlling system is the communication with the owner. Usually this happens with a number of LED´s that show the status of the battery, full charged, charging, or broken.

A more complex version of the charge controller would contain a MPP-Tracking, to make sure, that the PV-Module always runs with the highest possible power. This would lead to a higher energy consumption by the system itself, maybe even more, than it would bring in the end, and also to higher costs for the controller.[Qua15]If a MPP-Tracker is reasonable for this project has to be calculated in a later project with an optimization of the project.

The lifetime of a charge controller is information to be given by the suppliers.

A number of companies offer a huge range of charge controllers with different advantages and different prices.

2.1.3 Inverter

An inverter changes the DC-current produced in the PV-Modules and stored in the battery into an AC-current to supply the lamps and other possible consumers. It is only needed in a very big centralized system, because long distances need to be covered and the distances in a decentralized system are really short. In this system much more power would be wasted to change from DC to AC than the losses in the cables would cover. Where as in a big centralized system the ways are much longer and a lot more energy can be saved by an AC-current. A part form that, security is an important issue. AC-current is more secure than DC-current. An explanation would be too much for this study. Whether a AC or DC net would be more suitable needs to be calculated again before the actual planning process. [DGS13]

2.1.4 Battery

Also for the batteries a number of technologies have to be mentioned.

An older technology is lead-acid-batteries. Since they are mainly used in cars they are very common everywhere and still the cheapest possibility. Also recycling of those batteries is easier, as they only consist mainly of lead, and not a conversion of different materials. A problem is the high temperatures, which decrease the lifetime of the battery a lot and may also lead to the explosion of the battery. Therefore a ventilation in the pole would be necessary, to make the system more secure also under extreme weather conditions.

A newer and therefore a bit more expensive technology is Lithium-Ion-Batteries. But with their increasing popularity especially for electric vehicles the prices decrease regularly. Also for this technology high temperatures could make the battery explode. The temperature should also not fall under 0°C, but this should not be a problem in Uganda. For a high lifetime of the battery only 30-70% of the capacity of the battery should be used. Therefore also the capacity of the whole system needs to be increased. A disadvantage is, that recycling of the batteries is quite complex, as a large number of materials is used here. [SS16]

For this project a Lithium-Ion-battery would be best. Even so the prices are a bit higher, they last much longer, and are also safer than lead-acid batteries.

2.1.5 Lamp

Illuminates or lamps change electrical power into visible radiation and heat. The ratio of Lumen (light) and Watt (Heat) shows the efficiency of a lamp. Three different ways of producing light can be defined:

- by increasing the temperature (thermal radiator)
- by gas discharge (discharger lamp)
- by electrical processes (LED)

For a long time thermal radiators and discharger lamps were the dominant technologies on the international market. But due to their higher efficiency and a longer lifetime, the ratio of LEDs increases. Picture 2.2 shows the different types of lamps and compares their lifetime in hours and their light efficiency in lm/W. LED's have a long lifetime and a good light efficiency and should be the first choice for this project.

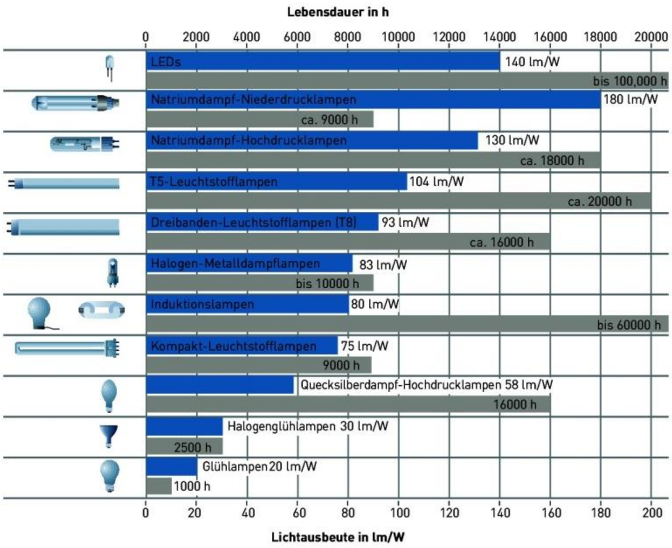

Figure 2.2: Comparison of different lamps with their lifetime and efficiency [tri19a]

To get a better understanding for the different kinds of lamps, some basic words need to be defined.

The LAMP LIGHT OUTPUT shows the ratio of the emitted amount of light to the input of electrical power of a free standing lamp under standard conditions. For the final use of LEDs cut-in units a needed, which also consume some power. The SYSTEM LIGHT OUTPUT shows the ratio, also considering these units.

In theory the maximum light efficiency reaches 683 lm/W for white light. The latest LED-Lamps already reach a light efficiency of 130 lm/W. [tri19a]

The LUMINOUS COLOUR is given by the most similar colour temperature T_{cp}. It shows the temperature of heated platinum, which colour perception is the same as the one of the light source. Low temperatures describe a warm, yellow-red-white colour, high temperatures belong to cold and blue light.

Which colour is needed in which context depends mainly on local customs and has no basic rule in Europe. In warmer climates usually a higher temperature is preferred. [tri19b]

Another issue for LED-lamps is the temperature of the environment. As a semiconductor, that translates electrical power, a LED is quite temperature sensitive. Especially the usual operating temperature in the lamp is important. In data sheets it is usually set up with 25 °C as the surrounding area. A higher temperature has a negative impact on the lifetime of the lamp.

Especially the LUMINOUS FLUX decreases during the life of the lamp. A complete outage of the lamp only happens after a very long time. A unitary lifetime for LED-Lamps is not defined.

For this study the needed power is defined for the lamps depending on how much light is needed to illuminate the street or area.

2.2 Comparison of the systems

For the project three different concepts are reasonable, as already mentioned above. Here the different systems are explained and compared.

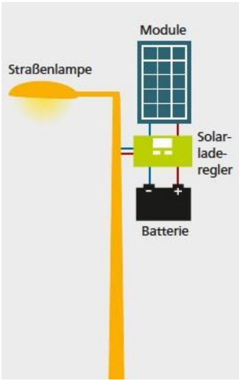

Figure 2.3: Scheme of a decentralized system [dec19]

Picture 2.3 shows how a decentralized system can be build up. In this system every lamp has its own PV-Module, a battery and a charge controller. These lamps are then installed along the roads wherever they are needed.

Another possible system is here called a decentralized system. In here one big PVModule supplies one central battery. The whole system gets controlled by one bigger charge controller which also gives information to the user. The lamps then are connected to the central module by cables.

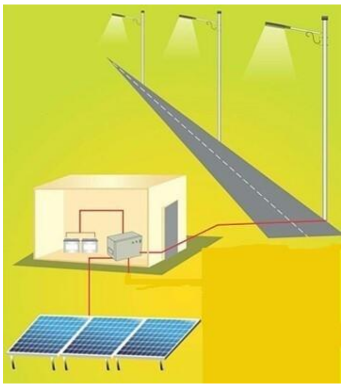

Figure 2.4: Scheme of a centralized system [cen19]

Both systems have different advantages and disadvantages. All these are explained and listed in table 2.1. A centralized system requires much more planning to ensure a efficient work of all installed components. The size of the battery needs to fit with the PV-panels to make sure, that no energy is wasted. Also the number of the lamps needs to be calculated for this special system size to ensure an optimal work. This requires a lot of planning and simulation to get the fitting size and it makes much more sense to install everything at the same time. This requires then a lot of money in the first place. To expand the system later the PV power plant needs to be expanded and the battery and the charge controller need to be changed.

On the other hand is it much easier to control and monitor the centralized system, because all the important data is collected in one place, probably Kayunga Town Council, and can be evaluated there. But a broken cable in this central station may cause a blackout in the whole city.

An important argument is environmental influences on the components. Especially the batteries suffer with high temperatures on top of the lamps. The boxes usually don´t contain a cooling system so the temperatures in side can get quite high. This reduces the lifetime drastically so they have to be replaced after a few years what leads then to increasing costs over a longer time. The costs are explained in detail in chapter 7.

2.3 Simulations

The simulation shall give a closer look to the different systems. All the circumstances are collected in this simulation and give an overview of what is feasible. As a simulation for a decentralized system makes no sense, only the centralized system is calculated.
The software PVsyst was used for this simulation.

Type of system	Centralized system	decentralized system
Advantages	Maintenance and monitoring is easier, as all the needed data is collected in one central place	No cabling is needed to connect the lamps, what reduces the effort of installation
	Only one central battery pack, module and controller has to be used, so less components can be destroyed.	easier to install, as no cables are needed and less holes need to be digged to provide the cables
	More secure, as components can be stored in one place	easier to expand as less planning is needed.
	Components live longer as they are not exposed to all weather conditions	
	Components can be calculated smaller, as the energy can be supplied to all lamps	
Disadvantages	Cabling has to be used and they have to be hidden in the earth	higher wind load on the single lamps because of the modules on top of the lamps
	Installation takes longer, because of cabling	batteries get hotter in the pole as they are exposed to the sun without cooling
	More difficult to expand, as more planning is needed to ensure a running system	maintenance and monitoring is more difficult, because every lamp has its own system
	One failure can destroy the whole system until it is repaired	

Table 2.1: Comparison of a centralized and decentralized system

2.3.1 Requirements for the simulation

Some restrictions and conditions need to be defined to explain the results.

- WEATHER DATA AND HORIZON LINE: For a simulation weather conditions need to be defined. PVsyst offers the needed data only for a low number of cities. For this study the data of Kampala was used as it is closest to Kayunga:
- ANGLE AND AZIMUTH: For this simulation data of Kayunga Town Council building was used. The angle of the roof is about 20° and the azimuth about 100°. The same data was also used for the building in Bukolooto, as there is no other data available at the moment.
- NUMBER OF LAMPS: The number of lamps was given by KTC and is listed in the tables 3.1 and 3.2. The distance between the lamps was decided with 30 m, which leads to a specific number in every road.

- POWER OF LAMPS: Three different types of roads where discovered for this study, and therefore different powers of lamps where used. For larger streets a power of 60 W is reasonable to illuminate the whole street. For smaller roads 40 W a enough and for small lanes only 30 W are necessary to illuminate it. Which type of lamp is needed for which street is listed in tables 3.1 and 3.2.
- DURATION: The streets are illuminated for 11 hours every night. From7 PM until 6 AM. It is possible to reduce these times by switching off the lamps for a few hours every night. This would reduce the needed capacity of the batteries and the power of the PV-Modules and would therefore lead to lower costs for the system. On the other hand then of course the streets are dark again for these hours and the risk for accidents or crimes during this period is rising again. It would also be possible to only switch off every second lamp, and for example change these after a few lamps. This scenario is not calculated in this study.
- SYSTEM VOLTAGE: For the battery a 48 V-level is reasonable.
- DAYS OF SYSTEM INDEPENDENCE: On cloudy or rainy days there might not be enough sunlight to fully charge the batteries. Therefore the lamps can be switched off in the middle of the night, because there is no power left. To reduce the number of dark hours the capacity of the batteries and the power of the modules needs to be increased. This would also increase the costs of the whole system. To keep those costs as low as possible, a system independence of one day was chosen for this study.
- CABLE LOSSES: To keep cable losses at a minimum, a maximum cable length of 2 km was advised by a member of Kirchner Solar Group. This leads also to a maximum radius and therefore to a maximum number of lamps. It is then possible to supply Kayunga with modules on the main building of Kayunga Town Council.
- MODULE POWER: with all these given parameters it is possible to simulate a certain module power for a scenario that is needed to fulfil the given requirements. A higher number of lamps or a higher power for these will increase the module power also the duration for the lamps to shine influences the power.
- BATTERY CAPACITY: Also the capacity for the battery can be calculated within the simulation. Especially the system independence increases the size of the battery, but the other values influence it, too.

2.3.2 Results of the simulation

The simulation was split into two parts for Kayunga (scenario 1 & 2) and Bukolooto (scenario 3 &4) and into two different time ranges with 11 h from 19.00 till 6.00 and with 6 h from 19.00-23.00 and 4.00-6.00. The results are shown in table 2.2.

Its clear that especially the operating time has a high influence on the needed power of the PV plant. Especially between scenario 3 and 4 the power is reduced by 50%. And of course there is a difference between the two cities of Bukolooto and Kayunga and its different numbers of lamps.

On the other side the battery size stays always the same with 2144 Ah. The reason for this can be found in picture 2.6. There is always a lack of energy to completely supply the lamps during the whole night. In scenario 2 and 4 this value is lower than in the other two scenarios so the battery is fitting to these.

These simulations were done without any optimization to the whole process so it would be possible to decrease these in a later process. Right now the module power and the battery capacity are quite big and therefore also very expensive.

	Lamps	Time	Power PV [kWp]	Battery capacity [Ah]
scenario 1	85 - 40W / 7060W	11 h	30,6	2144 Ah
scenario 2	85 - 40W / 7060W	6 h	19,8	2144 Ah
scenario 3	57 - 30W / 6060W	11 h	18,9	2144 Ah
scenario 4	57 - 30W / 6060W	6 h	9,9	2144 Ah

Table 2.2: Results of the simulation of a centralized system

Figure 2.5 shows in detail the hourly profiles for 11 hours or 6 hours. As the load is constant during the whole time of operation, these profiles are quite easy to prepare.

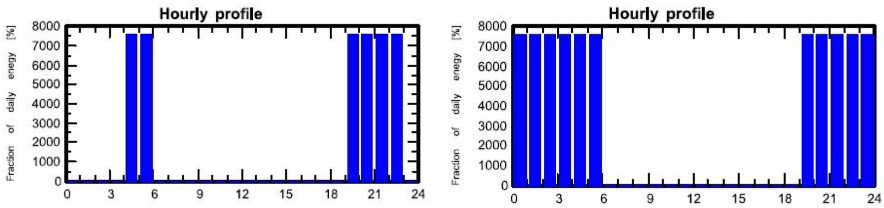

Figure 2.5: Hourly profiles 6h and 11h

Figure 2.6 shows one example for the simulation results. Here is scenario 1 explained. In dark blue is the available energy every month shown. It depends mainly on the coming radiation and changes through the year. In red, the unused energy, that is available during the day, when the battery is already full. As can be seen in the figure this is quite a lot, so it would make sense to think about other uses for this energy, that are plugged in, when the battery is full.

In grey on the other hand the missing energy is shown. This energy is needed, when the battery is empty. It would be ideal to keep this value as low as possible to supply the lamps during the whole night. In the other scenario this graph is quite often 0, but this scenario has the highest number of lamps and 11h to supply. So many more batteries would be needed to lower this graph, which would lead to exploding costs.

The yellow graph shows the used energy, while light blue is the needed energy. The difference between these two is then the missing energy in grey. These values should be as close together as possible. And as the load does not change through the year, especially the load should be more or less constant.

It is especially interesting to sum up the numbers for the missing energy every year. In scenario 1 this would lead to a missing energy of 4.5 MWh every year. If this power is not supplied with any other technology, there will be no light provided for a certain time. In scenario 2 this is only 0.27 MWh. In scenario 3 about 1.9 MWh are missing and in scenario 4 0.44 MWh. With the constant battery size of above, it can be observed that shorter operating times lead to less missing energy every year. So it comes to one's mind to increase the size of the battery for the scenarios 1 and 3, but this would of course also increase the costs again.

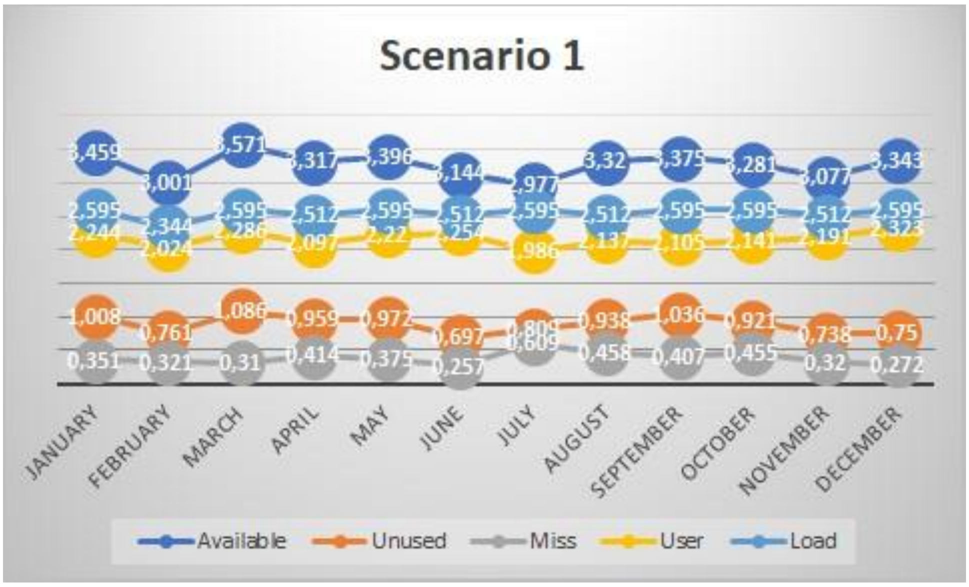

Figure 2.6: Simulation results for Scenario 1 in MW

Chapter 3

3 Geographical conditions and feasibility of installing street lamps

The following chapter will assess the general conditions of the roads, streets and lanes in terms of installing street lamps in the two areas of Kayunga central ward and Bukolooto ward. The general feasibility of installing a centralized and a decentralized street lamp system was examined. Depending on the factor if it is a road, street or lane different amounts of Watts (W) for different illumination necessities were chosen. For roads 60W, for streets 40W and for lanes 30W with each 30m distance in between the lamps were chosen. These values are based on experiences of other projects and company advises and are not finally fixed. The selection of the observed streets was made by the Kayunga Town Council, and there is no specific order in the list of streets.

In accordance with these conditions, the following amount of street lamps was determined for Kayunga Central Ward and Bukolooto Ward:

Road	Distance	Number of Lamps	Power
Mumyuka	400 m	13	40 W
Kalya	1200 m	40	40 W
Sekagya	200 m	6	40 W
Rwamirego	100 m	3	40 W
Church	600 m	20	40 W
Kampala	1500 m	50	60 W
Busaana	600 m	20	60 W
Hospital Lane	100 m	3	40 W
Sum		155	70 times - 60W 85 times - 40 W

Table 3.1: Distribution of lamps in Kayunga Central Ward

So 155 street lamps with 30m in between were determined for Kayunga Central Ward. In detail they are separated in 70 lamps with 60W each and 85 lamps with 40W each. So 116 street lamps with 30m in between were determined for Bukolooto Ward. In detail they are separated in 59 lamps with 60W each and 57 lamps with 30W each.

Road	Distance	Number of Lamps	Power
Kampala	400 m	13	60 W
Kayunga	600 m	20	60 W
Jinja	800 m	26	60 W
Kizuungu	600 m	20	30 W
Pastor Ian	300 m	10	30 W
Kabonge	200 m	6	30 W
Market Place	150 m	5	30 W
Madada	100 m	3	30 W
Rufla	400 m	13	30 W
Sum		166	59 times - 60W 57 times - 30W

Table 3.2: Distribution of lamps in Bukooloto Ward

In addition, an overall amount of 271 street lamps for whole Kayunga was calculated. In detail there are 129 lamps with 60W, 85 lamps with 40W and 57 lamps with 30W each.

3.1 Overview of obstacles for street lamps

On the roads are several obstacles that could disturb or interfere with the solar street lamp systems. They shall be explained and introduced here.

Figure 3.1: Example for an electrical Power Pole

The wires of the poles could interfere with a solar street lamp system. If these electrical power poles would fall down, they could also cause serious damages.

Figure 3.2: Example for a road reserve

To place the street lamps on the roadside, it needs to be assured that the road reserve is not too small and that there is enough space.

Figure 3.3: Example for trenches

On several roads are trenches on the roadside. To provide enough light these trenches have to be bridged over by the street lamp pole, so that there is enough light on the road.

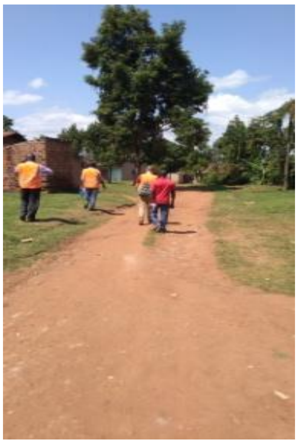

Figure 3.4: Example for trees

In case of a decentralized system, trees on the roadside can shade the pv panel of the system. Shading of the panel can cause massive losses in the yield, so that a stable illumination in the night can maybe not be provided.

3.2 Conclusion for Kayunga Central Ward

For Kayunga Central Ward all obstacles like trenches, electricity poles, small road reserves and trees are probably possible to elude. Moreover, there is a highly promising area to put a centralized system for supplying the whole Kayunga Central Ward, located around the KTC and on the top of the KTC building. This is rooting in the ownership of this place by the KTC and potentially a good security in the night, because there are night guards anyway. Also, the KTC building is not too far away from the streets to be supplied, so there would not be too much cable losses. OVERALL GENERAL FEASIBILITY FOR A DECENTRALIZED AND A CENTRALIZED SOLAR STREET LAMP SYSTEM IS GIVEN.

Figure 3.5: Map Kayunga Central Ward

3.3 Conclusion for Bukolooto Ward

In the Bukolooto Ward most obstacles like trenches, electricity poles, small road reserves are probably possible to elude. For the potential realization of a decentralized street lamp system a lot of trees at the lanes could affect the system yield due to shading and they need to be cut down. Concerning a centralized system solution, an own area to put the system is needed, because a connection to a potential system in Kayunga Central Ward is due to the distance and the related cable losses not recommendable. A potentially suitable area for a centralized system was found near the Bukolooto substation, but the ownership is unclear and with that the possibility to rent or buy it. As a result of our investigations, a general feasibility for a decentralized and a centralized system can only be given with the above mentioned open points solved.

3.4 Community spots for street lamps

Beyond the placing of the solar street lamps on the priority roads, there are other potentially useful locations to put them. These locations could be especially relevant for the everyday life of the community of Kayunga and putting lamps there might improve it. After interviewing some residents of Kayunga and Community leaders we can name some spots to place street lamps:

- Market areas (Central, Kizunga and Bukolooto)
- Taxi Park in Kayunga
- School Courts (because some students sleep in the school buildings)
- Road through the swamp between Kayunga Central Ward and Bukolooto. These spots are not necessary the best locations for street lamps, it is just a collection to help to start thinking about the topic. A more profound identification of the spots should be done by KTC in close collaboration with Community of Kayunga.

Chapter 4

4 Maintenance and Recycling of broken components

As already said most of the components need to be replaced with in 20 years, so the question is how has the maintenance to be done and what will happen with the broken components?

4.1 Maintenance

To provide an optimal yield for a solar based system, monitoring and maintenance on a regular basis is inevitable.

As in Chapter 2 already mentioned, there are yield losses due to dust or dirt on the panels that need to be avoided. Therefore a regular cleaning scheme for the modules is recommend. This is within the rainy season, or if there is regular rainfall in general not required.

Furthermore a monitoring system for the system yield, e.g. provided by a communicating charge controller would be helpful to detect any kind of problems. The controller would communicate via Internet then to the supplier (or even the customer if requested) if there are any issues with energy output of the system. These charge controllers which are able to communicate the system status are more costly, so that they are probably only make sense for a centralized system where all the batteries and PV modules are at one place. For a decentralized system, every street lamp unit would need an own charge controller and this would lead to by fare higher costs. As a result of this, some kind of community monitoring should be organized for decentralized system, where the residents give feedback to the KTC if a lamp is not providing enough light. In accordance with the suppliers a general procedure for occurring malfunctions should be determined in advance, either for procuring replacement parts (if the maintenance is done by the Town Engineer for example) or for sending a technician to fix the problem. Another idea would be, to identify the parts with the highest failure rate in advance and store some replacement parts for them in Kayunga.

4.2 Recycling of broken or old components

4.2.1 Batteries

The recycling of old batteries is not only important for the protection of the environment, it is also an issue for general safety. I f a Li-Ion Batteries get in touch with water, Lithium-leach and Hydrogen is formed. Hydrogen is quite inflammable and causes damages and risks for the population. Also for this reason, it is very important to protect these batteries from all kind of water, also in the case of a fire! Especially old batteries can be very dangerous and educated employees are needed to collect them.

Also Li-Ion batteries include some valuable components that should be collected and reused, like cobalt, copper, nickel and lithium. More than 90% of the used cobalt, copper and nickel can be reused with the right process. With the next step also most of the lithium can be collected and recycled. Copper cables, boards. plastics and the steel casing are just reused.

Asante Waste Management provides a battery recycling programme across Uganda and East Africa to collect used batteries of different kinds, like lead acid or lithium Ion batteries. Closer information can be found here: http://www.asantewm.com/batteryrecycling-disposal/. Apart from that, some companies organize their own collection service like trust power.

4.2.2 PV-Panels

PV-Panels cause less danger for the population, but can be quite dangerous for the environment. Especially cracks in the protection glass can be dangerous. Water can then reach into the module and rinse toxic metals that are needed for the process.

Also a high recycling rate of about 80% is reachable. As the main components are made out of metal, plastics and glass it is easy to separate and reuse them for new panels.

Broken components are usually also collected by the supplier.

Chapter 5

5 Observation of existing street lamp projects

To acquire as much reliable information as possible with a neutral feedback for the system behaviour in operation and also potential problems, a decision was made to benchmark existing solar street lamp systems in other cities in Uganda. In accordance with the Kayunga Town Council the cities of Fort Portal and Entebbe were selected for this purpose. To get a structured and standardized feedback, a question list for benchmarking was created (see attachments). The question list is categorized in this four sub items: - General information and system specifications - System costs - System performance and in usage and performance - Planning and realization process This answers were collected:

5.1 Assessment of the solar street lamp system of Fort Portal

The decentralized solar street lamp system in Fort Portal is operating for around one year now with a serial of mention worthy criteria. The used system configuration provides stable illumination on almost every day of the year for a decent price of 5.2 – 7 Mio. UGX per lamp. The financing of the project was mainly done with governmental money, consisting out of fixed funds from the Ugandan Road Fund and the World Bank Road Fund. In addition to this, the administration of Fort Portal involved local companies and business for funding street lamps nearby their location. Within the time of operation of the system's two main problems occurred. First, there was a huge series of defectives of the photo sensors, because the sensors did not recognize the setting of the sun. This led to the issue that the lamps did not turn on in the night, which caused a massive replacement. Secondly, there were cases of theft for lamps which were located in remote areas. As a result of our system observation we recognized another potential big issue: the storage of batteries. These are stored in metal boxes without cooling system, which are attached to the pole. Due to the temperature sensitivity of batteries, this storing location will probably reduce the lifespan drastically and leads to a complete replacement after a short time.

In conclusion, the decentralized system of Fort Portal has some useful basic approaches, like the stable illumination for a relatively low price and the idea to involve the community in the funding process. Based on the short utilization period of the system, it is not possible to assess further technical circumstances and if the low price is a real benefit. The storing of the batteries inside of metal boxes on the pole is something that needs to be avoided for similar system configuration in Kayunga.

5.2 Assessment of the solar street lamp system of Entebbe

The solar street lamp system in Entebbe is also a decentralized one, and has a lot of technical similarities with the one in Fort Portal. A big difference compared to Fort Portal is the utilization period of the system, because the first solar street lamps in Entebbe were built in 2013. This fact leads to a more reliable feedback concerning the component malfunctions, since there was a lot more time for observing the system behaviour and potential problems. The used system configuration in Entebbe provides stable illumination though the whole night too, but it is with around 9 Mio. UGX per lamp more costly. This could be explained with the fact, that there was a price decrease in solar components in the last years, and the Entebbe system is just older. Financing of the project was also done with Ugandan Road Funds and World Bank Road Funds. Main issues were here also not properly operating photo sensors and theft. Furthermore a few cases occurred, where the street lamps were damaged by cars. For storing the batteries, there are two solutions in Entebbe. The previous mentioned metal boxes on the pole and putting the batteries into concrete in the ground. This method could extend the lifespan of the batteries compared to the storage in the boxes, because there is a lower heat load. Nevertheless, storing the batteries in the concrete is also not an optimal solution, because there are still high fluctuations in temperature.

Overall, the system of Entebbe works for a long time now, but there is, unfortunately, a lack of monitoring and detailed failure statistics. Due to this, there is only information about the main problems and malfunctions of components, but not their amount and the average lifespan per lamp.

Question	Fort Portal	Entebbe
1. What kind of system do you use (centralized/ decentralized/ mixture)? What was the reason to choose this system configuration?	Uses decentralized system, but with plans for a centralized system in the city core. Reasons: system is easy to expand (every time they have money they can buy new lamps), high initial costs of a centralized system, higher planning effort for a centralized system.	Uses also a decentralized system. Reasons: a decentralized system is more reliable in the sense of blackout danger, a huge centralized system with a lot of wiring would be needed to supply all lamps in the city
2. What are the specifications of the system?		
2.1 Since when you have the system?	1 year	5-6 years
2.2 illumination power and area of the lamps:	60W	Depending on area (road: 40W 4100 lm, lane: 20W)
2.3 battery size	130 Ah	250 Ah
2.4 Number and power of the pv modules that supply them:	2 panels with 100 W each	2 panels with 80 W each
2.5 size of the system (amount of lamps, km)?	unknown	unknown
2.6 pole height and distance between the poles?	height: 22ft with 6" diameter; distance: 30 – 35m	25 -35m
2.7 hours of operation (from dusk till dawn or specific amount of hours per night)?	Whole night	Whole night
3. Which company was the supplier for your system? Which other companies were involved? What was the reason to hire these specific companies? Would you recommend them?	"solarstar" based in Fort Portal. The choice was made after a public bidding process, based mainly on costs but also on capability.	a lot of different companies/ contractors are involved. For every extension and new street, they start another bidding process.
4. Is there any kind of security concept for the lamps?	batteries are welded inside of metal boxes which are lifted up at least 3m height of the pole. Some are also digged in the ground and fixed with concrete.	same concepts as in FP but without welding. Alternatively the, but the batteries in concrete in the ground.

Table 5.1: General information and system specifications in Fort Portal and Entebbe

Question	Fort Portal	Entebbe
7. How does the system behave or operate in everyday usage?	They provide usually enough light for the whole night. Only in 2 or 3 days per year they don´t do, if there was almost no sunshine before.	they provide usually enough light for the whole night (unfortunately no more information)
8. What are your problems in everyday usage?	Main issues with the sensor/ photo cell (had a defect) and with theft (for lamps which are placed a little bit offside)	Main issue is the photo cell too (defect)
9. Who is providing the maintenance for the system (town, supplier or other company)?	the installer provides all the maintenance	maintenance is done by subcontractors
10. What are the usual maintenance tasks for the system and how often you have to do them (e.g. cleaning of the modules)?	only cleaning of modules (once a year). Other tasks are only replacing defect or stolen system components	no cleaning of the modules (explanation: enough rain. But unsure if they know how dirt affects the module performance), only replacing defect or stolen system components
11. Do you have any kind of monitoring system for components or the whole system? If so what kind of monitoring?	no monitoring system, works only with reports from community if there are lamps not working properly	same as in FP
12. What are critical components in the sense of maintenance or replacement? Does the supplier offer any kind of guarantee/ replacement or recycling for those components?	critical components: photo cells, bulbs, batteries. 2 years guarantee for all components	critical components: photo cells. 1 year guarantee for all components.
13. When was the first replacement needed, and which part was broken?	photo cells, no specific time/date was given (after some months)	photo cells, no specific time/date was given

Table 5.2: System Performance and maintenance in Fort Portal and Entebbe

Question	Fort Portal	Entebbe
5. What were the overall system costs (components, installation/construction)?	5,2 – 7 Mio. UGX per lamp	9 Mio. UGX per lamp
6. What are the operational system costs (cleaning/ maintaining/ replacing)?	150k Shillings service and replacement budget per lamp	no information

Table 5.3: System Costs in Fort Portal and Entebbe

Question	Fort Portal	Entebbe
14. How long was the overall planning and realisation time for the system? How much of that planning/realisation?	Realisation time system: 1 month; overall (with open domestic bidding process): 3 month	No information
15. What were the longest parts within those processes? What were your main challenges and problems?	Longest parts: drying of the cement base (3 weeks)	No information
16. Who was doing the installation/construction work? What were the main difficulties within that work?	local construction companies in cooperation with solarstar. No difficulties mentioned.	contractors. No difficulties mentioned.
17. How long was delivery time for the components?	Under 2 weeks	No information

Table 5.4: Planning and realisation process in Fort Portal and Entebbe

6 Company visits and procurement analysis

To get a better understanding of the Ugandan market for solar technology and for the possibility on our side to make mere cost estimations for a potential street lamp system, we approached different Ugandan companies. The selection of these companies was made as a result of recommendations, either on the side of members of the Kayunga Town Council, our visits in other cities or by the GIZ office in Kampala.

We contacted the following companies:

- Davis & Shirtliff (Nairobi/ Kampala)
- Solarstar (Fort Portal)
- Solarnow (Kampala)
- Powertrust Eastafrica (Kampala)
- Mafarini Energy (Kampala)
- Kirchner Solar (Luuweero)

Out of these companies, only POWERTRUST EASTAFRICA, SOLARNOW and KIRCHNER SOLAR responded or communicated to us in a sufficient and reliable way, so we decided to analyze them in more detail and use them for our information acquisition. For this matter we created a wide-ranging question list (see appendix 11) as a basic structure of our further visits and correspondence.

6.1 Powertrust Eastafrica

6.1.1 General information and experience

Powertrust is a medium sized company with 25 employees located in Kampala (Ntinda). They have experience in building solar street lamp systems since 2013 and realized plenty of projects in this field. Powertrust designs the systems for the customer, also based on their wishes and provides the installation work. They are specialized in decentralized solar street lamp solutions and prefer them because they have (from their perspective) lower costs and a smaller blackout risk. Their portfolio also contains centralized street lamp solutions, but they only realized one of these systems in South Sudan. Due to this, most of their information is only related to decentralized systems.

6.1.2 Components and costs

Powertrust sources its components from various suppliers from different companies. They gave us the following information about the components and their origin:

- Battery (Type: AGM, Supplier: Exil (India), Lifespan: 5-7 years)
- Lamp (Type: LED, Supplier: KEM (China), Lifespan: 30 – 50k hours)
- Charge Controller (Supplier: Phocos (Germany), Lifespan: 5-7 years)
- Panels (Supplier: Tunisian company; Lifespan: >20 years)

On all of their components they give 1 warranty, which covers workmanship and product failures. Their recommendations for lamp power and distance in between the lamps are 60W for roads and 40W for lanes by 25m.

In terms of costs it´s not possible to give exact figures without a concrete detailed request because it highly depends on the used components, but they provided us with their scope of services and rates. Their answers were only referred to decentralized systems, because of their lack of experience in centralized systems and their level of complexity. Powertrust calculates usually for the installation of a decentralized system with 10% of the material costs. There are no usual rates for transport costs, but an important factor there is the built of a base camp where the material is stored. They offer discounts for bulk purchases for orders with more than 8 poles. Services like cabling along the streets (for a centralized system) and digging of the pole holes is included in every price offer.

6.1.3 Installation and maintenance

The installation process is completely handled by Powertrust. With their workforce, they can place up to 12 poles of a decentralized system per day, if everything is in place. Longest part of the installation is the drying time for the concrete, this are 6 days.

Powertrust provides maintenance and service contracts for this. If malfunctions occur, they send a technician within 24 hours. They provided technical monitoring systems after customer request for an additional fee. The exact parts of the service contracts are always negotiated individually, but they always use local people which they train before (e.g. town engineer) for error feedback. They are also working together with a certified recycling company in Kampala, for bringing there the broken components.

There methods against theft of the components are welding of the PV panel in a frame and sealing of the batteries inside a chamber under the earth.

6.1.4 Conclusion

Powertrust seems to be a reliable company, with a cooperative and helpful staff. They have experience in decentralized systems, but almost none with centralized ones. This could be a reason for their really positive picture on decentralized systems and therefore an overrating of the system lifespan (especially for batteries) of this solution, because it´s their main business. On the other hand, they may also slightly overrate risks and costs of a centralized system, because this lack of experience there. Additionally, their values for lamp power and distance are different from the others we experienced so far. Their lamp power recommendation for lanes is relatively high and the distance in between the lamps smaller. Overall a company that could be a reliable partner to work with, but the previous mentioned points should be considered when making business with them.

6.2 Solarnow

Solarnow is huge company with more than 100 employees from Kampala (Kansanga), with experience for more than 9 years in solar systems. Unfortunately, they provided us with the wrong person to answer our questions. Our contact didn´t had a technical background and was not able to answer our questions sufficiently. Promises to forward our questions to technicians were not kept, so almost NO USEFUL INFORMATION were acquired at the end of our study.

6.3 Kirchner Solar

6.3.1 General information and experience

Kirchner Solar is a huge company with more than 100 employees and operating in several countries all over the world. They are founded in Germany and their main office is also based there. Kirchner gained expertise in the engineering and installation of solar systems for more than 20 years and has quite a lot of experience in large scale solar projects in whole Africa. In Uganda, Kirchner is mainly testing solar solutions and provides education and training for students. They have ALMOST NO ACTIVE BUSINESS IN UGANDA, only on demand for special projects. When it goes to street lamps, they only provide centralized solutions and completely refuse decentralized solutions. Their refusal of decentralized systems is based on bad experience in the past, especially when it goes to the battery lifespan, which is affected by the high temperatures inside of the metal boxes of the lamp poles. Due to this, all their following information is only based on centralized street lamp systems.

6.3.2 Components and costs

Kirchner solar sources all of their components either from China or Germany. The level of quality is really high, because all of their components are tested and certified by TÜV, the German Association for Technical Inspection. For their components, they gave us the following information on technology and lifespan:

- Battery ((Type: LiOn, Lifespan: up to 15 years) or alternative*: Type: Acid Redox battery, Lifespan: up to 10 years
- Lamp (Type: LED, Lifespan: 10 – 40k hours)
- Inverter (Supplier: SMA (Germany), Lifespan: 20 years)
- Panels (Origin: China; Lifespan: 20 - 25 years)

On the components Kirchner provides different warranty time frames, for inverters 5 years, for panels 20 years and for batteries 2 years. Their recommendation for the maximum distance between central battery units and the connected lamps is 2 km because of cable losses. They recommend 30m distance between the lamps and use within the system a voltage level of 220V with AC.

In terms of costs an estimate for a centralized system is not possible because detailed planning in advance is necessary. There are also no fixed rates for material costs, cabling or other cost factors. Based on their experience they shared with us their price frames of less per lamp, for projects bigger than 30 lamps.

**sourcing of high quality Li-Ion batteries is difficult for Ugandan companies at the moment, because of the high demand for these batteries for electric cars.*

6.3.3 Installation and maintenance

Only the planning, engineering and monitoring will be provided by Kirchner Solar. All technical parts are tested in Germany and will be shipped to Uganda. For the installation and the production of easy parts like poles, they usually work together with local companies and supervise them. A time frame for different processes or an estimate for the whole installation was not given by them.

Monitoring of the system and fixing of usual malfunctions is done remotely from Germany, with possible support from the customer or local installers. For serious problems an engineer from Germany has to come to Uganda for fixing it.

6.3.4 Conclusion

Kirchner Solar is highly professional and experienced company when it goes to all kind of solar system solutions. They have experience with both types of solar street lamp solutions, centralized and decentralized systems. The fact that they completely refuse decentralized solutions because of the battery lifespan problems is an important point, that should be kept in mind when approaching any kind of other company. But nevertheless Kirchner could also slightly underrate the lifespan of the batteries in decentralized system, because these solutions do not fit so well in their usual mostly planning and engineering based range of services. Another point that should be memorized about them, is that they almost don´t have any active business anymore in Uganda, so that they probably only take big jobs. Overall a most likely professional and reliable partner, but because of the fact, that all the planning is done in Germany and the components are also shipped from there in combination with the high initial costs of a centralized system, it is expensive in the beginning, so that a lot of capital is necessary to get started.

7 Cost estimation for the Systems

To support KTCs decision also the financial aspect for the whole project is important. In this chapter the most important costs split up for the different systems are going to be collected and compared. Not only the costs for the components are collected in here, but also costs for the installation work, the maintenance, the cleaning of the modules and the replacement of broken parts.

7.1 Price list from the systems in Fort Portal and Entebbe

As a result for the visits in Fort Portal and Entebbe also price lists for their systems where given. Table 7.1 shows the prices for one lamp paid in Fort Portal and Entebbe. It is quite obvious that the system in Entebbe is much more expensive than the one in Fort Portal. This can be because of the different ages of both systems or of different suppliers. Unfortunately the prices for each component are not listed for Entebbe, so it cannot be named which components cause this huge difference.

7.2 Offer by Power Trust

7.2.1 Installation Costs

Table 7.2 shows an offer by the Ugandan company Power Trust that was introduced in chapter 5. The offer was made on 4th October 2019 for a certain amount of lamps. The offer describes a decentralized system with the amount of lamps as given in chapter 3. Table 7.2 only shows the prices for a 30 W lamp. The offers for 40W and 60 W lamps can be found attached.

All components listed in this chapter and in the offer are over sized because of different reasons. First of all especially the battery and the PV-module loos capacity or power during their lifetime. To ensure enough light also after a longer time these components need to be oversized in the beginning. Also dust and other dirt will cover the PV-panel and reduce its power as explained in chapter 2.1.1. To ensure enough power for the lamps most of the time the PV-module needs to be installed bigger than actually needed.

Component	Description	Fort Portal (UGX)	Fort Portal (€)	Entebbe (UGX)	Entebbe (€)
Pole	6,7 m / 9 m	1.400.000	341		
LED	60 W / 40 W	764.000	186		
2 panels	100 W / 80 W	800.000	195		
battery	130 Ah / 250 Ah	900.000	219		
charge controller		700.000	170		
battery box		150.000	36	-	-
Wire		60.000	14	-	-
Base Bolt		150.000	36	-	-
Claps		10.000	2,4	-	-
labour installation		180.000	44	-	-
solar parts replacement		150.000	36	-	-
construct concrete block		-	-	500.000	122
in total		5.246.000	1279,4	9.250.000	2.258,26

Table 7.1: Prices in Fort Portal and Entebbe per lamp

If the price in table 7.2 is compared with the prices in Fort Portal and Entebbe in table 7.1 it can be seen, that this offer is a bit more expensive than the one in Fort Portal but cheaper as in Entebbe. Only the charge-controller is here cheaper. The price differences are probably caused by the different suppliers and the installation times.

Table 7.3 shows the prices for the number of lamps as estimated in chapter 3. Also the prices for transport to Kayunga and the installation are included here. These prices where given for this certain amount of lamps and not per piece.

Table 7.4 shows the estimated costs, if only Kayunga was equipped with street lamps. The numbers for one lamp where calculated with the prices from table 7.3 to include also transport and installation. If these prices are not linear, the costs for the Kayunga might increase a bit. About 54% of the costs are needed for the installation in Kayunga.

Unit	Component	Number	Price UGX	Price €	Warranty
150 Ah	Battery	1	1.500.000	368	2 years
30W	LED-Lamp	1	850.000	209	2 years
120 W	Solar Panel	1	1.200.000	295	25 years
	Solar Cables	24	288.000	70	
20 Amps	Charge Controller	1	250.000	61	1 year
	Pole	1	1.900.000	467	
	Battery Chamber	1	350.000	86	
	total		6.388.000	1559	

Table 7.2: Price List Offer by Power trust for one 60W lamp

	30 W	40 W	60 W	in total
Number	57	85	129	271
price one	5.243.840	5.931.840	6.947.840	
price all	298.898.880	504.206.400	896.271.360	
installation	23.911.910	40.336.512	71.701.709	
transport	2.500.000	3.500.000	5.00.000	
Sum (UGX)	325.310.790	548.042.912	972.973.069	1.846.326.771
Sum (€)	80.073	134.897	239.491	484.461

Table 7.3: Price calculation for a decentralized system

7.2.2 Costs for broken components in 20 years

Especially for a decentralized system the maintenance costs will be relative high. The batteries need to be replaced regularly and also the other components reach the end of their life earlier because of environmental influences. A short estimation for theses costs are given in table 7.5. These costs are not based on a specific offer by a company, they are calculations by the authors based on the general offer as explained in table 7.2 and may differ in reality. Also these costs are only for broken components. It may happen that some components are stolen and need to be replaced earlier. This is not calculated here. Also the prices for all the components may de- or increase during the next 20 years. This can also not be calculated in this first estimation.

The following assumptions where made for this calculation:

- Batteries have to be replaced after 3 years due to the high temperatures in the boxes. This information is based on advices from different companies. They may last longer in an cooler and protected environment
- LED-Lamps usually last for 30.000-50.000 hours. The calculation was done with about 40.000h, when the lamp shines for 11 hours every night. This leads to a life time of about 10 years. The reduction of hours per night also increases the total lifetime of the lamp in years and can therefore lead to a cost reduction

	40 W	60 W	total
price for one	6.447.563	7.542.426	
number	85	70	155
price total (UGX)	548.042.912	527.969.882	1.524.055.706
price total (€)	134.897	129.956	264.853

Table 7.4: Price calculation for a decentralized system only in Kayunga

- PV-panel usually last for 20 years. They loos some power over the years, but usually not enough to replace them in the next 20 years.
- Charge-controllers usually have a life span of 5-7 years before the important parts are broken. Therefore after the first installation 3 more are needed.
- Pole, battery box, cable and other components should last for 20 years and don´t need to be replaced.
- This calculation does not include labour costs for the installation for the broken components. Also regular maintenance like cleaning modules and so on is not included.

The costs were calculated for 30, 40 and 60W lamps and with the number of lamps as given in table 3.1 and 3.2.

	Battery	LED-Lamp	PV-panel	Charge-Controller	total
replacement after	3 years	30.000-50.000h / 10 years	20 years	5-7 years	
number in 20 years after installation	6	1	-	3	
costs for one	750.000 UGX/ 184€	550.000 / 134 €	-	250.000 / 61€	
costs per year	225.500 / 55€	27.500 / 7€	-	37.500 / 9€	290.500 / 71€
costs over 20 years	4.500.000 / 1105€	550.000 /135€	-	750.000 / 184€	5.800.000 / 1424€
costs per year for 57 lamps	12.853.5000 / 3156 €	1.567.500 / 385 €	-	2.137.500 / 525€	15.558.500 / 4066€

Table 7.5: Maintenance costs for a decentralized 30W-lamps system

	Battery	LED-Lamp	PV-panel	Charge-Controller	total
replacement after	3 years	30.000-50.000h / 10 years	20 years	5-7 years	
number in 20 years after installation	6	1	-	3	
costs for one	1.200.000 UGX/ 295€	650.000 / 159 €	-	250.000 / 61€	
costs per year	360.000 / 88€	32.500 /8€	-	37.500 / 9€	4
costs over 20 years	7.200.000 / 1.768€	650.000 / 160€	-	750.000 7/ 184€	8.600.000 / 2.112€
costs per year for 85 lamps	30.600.000 / 7.520€	2.762.500 / 687€	-	3.187.500 / 782€	36.550.000 / 8977

Table 7.6: Maintenance costs for a decentralized 40W-lamps system

	Battery	LED-Lamp	PV-panel	Charge-Controller	total
replacement after	3 years	30.000-50.000h / 10 years	20 years	5-7 years	
number in 20 years	6	1	-	3	
costs for one	1.500.000 / 368€	850.000 / 208€	-	250.000 / 61€	
costs per year	450.000 / 110€	42.500 /10€	-	37.500 / 9€	530.000 / 129€
costs over 20 years	9.000.000 / 2208€	850.000 / 208€	-	750.000 7/ 183€	10.600.000 / 2599€
costs per year for 129 lamps	58.050.000 / 14.190€	5.482.500 / 1.290€	-	4.837.500 / 1161€	68.370.000 / 16.641€

Table 7.7: Maintenance costs for a decentralized 60 W-lamps system

7.3 Costs for a centralized system

For a centralized system no specific offer was given. It is therefore hard to give a certain number. Every price given in this chapter is therefore only an estimate by the authors with advices from others

Mr. Fan, contact in Uganda for Kirchner Group, estimated a price of 6.600.000 UGX to 8.830.000 UGX, this is about 1.630 € - 2170 €, per lamp.

Additionally it is possible to calculate or estimate prices with the simulation in chapter 2.3. With the needed components it is possible to find out their prices and then calculate the installation costs.

Also these components need to be replaced after some time. For the PV-module, the LED-lamp and the charge-controller the times will be the same as explained in chapter 7.2.2. The battery should last much longer when stored in a cooled and protected place. But without reliable data it is impossible to do a realistic forecast.

Chapter 8

8

Fundraising

Another important part for this project is the funding. Organizations, that support projects like this, shall be listed and described in this chapter

8.1 Servicestelle für Kommunen in der einen Welt (SKEW)

SKEW is also part of the NGO ´Engagement Global´ and therefore funded by the Ministry of Economic Cooperation and Development. They work together with municipalities in Germany in the case of international development cooperation projects. On one hand they offer a wide range of funds for different projects, but also support with a big network of experts and a lot of knowledge and experience. The interesting funds for this project are explained here.

Förderprogramm FKKP

This program supports especially municipal projects that work on climate protection and adaption. FKKP stands for 'Förderprogramm für kommunale Klimaschutz- und Klimaanpassungsprojekte', what can be translated with 'support program for municipal projects in climate change and climate adaption'. To get this support, the project has to be part of the project municipal climate partnership. The duration of the project has to be three years.

In the first step of the application a short description of the project has to be written, it is important to do that in close cooperation with the twinning town. After a positive reply, two months later, the full application has to be sent. It is possible and necessary to get support from the organisation during the whole process of the application. All necessary documents can be found on their homepage: (https://skew.engagementglobal.de/foerderprogramm-fuer-kommunale-klimaschutz-und-klimaanpassungsprojekte.html). Information about the amount of money was not given on the page.

Kleinprojektefonds kommunale Entwicklungspolitik

This fund is only for small projects that can be realized in one year. The amount is around 1000 - 20.000 €. It is mainly for first projects, and therefore not suitable for this project.

Closer information can be found on this page (https://skew.engagement-global.de/kleinprojektefonds.html)

Nakopa

Nakopoa is short for 'nachhaltige Kommunalentwicklung durch Partnerschaftsprojekte', what can be translated with 'sustainable and municipal development by partnership projects'.

This fund is especially for German municipals and municipal unions. They support projects that develop local solutions in global questions in the sense of the Agenda 2030, like sustainable existence support, good local governance, climate protection and adaptation.

Projects with a longer duration and shared project experience can get grants of about 50.000-250.000 €. Bigger projects with a good cooperation can also get subsidies of 500.000 €.

The application is also set up in two steps. Until January an expression of interest has to be send via E-mail and mail. After a positive answer the whole application needs to be send until May of the same year.

All necessary documents and dates can be found on the official homepage. (https://skew.engagementglobal.de/unterstuetzung-durch-nakopa.html)

The fire brigade of Kayunga was supported by this program.

8.2 Other public funds in Germany

8.2.1 BMZ and Schmitz-Stiftung

The BMZ offers different funding possibilities for smaller projects (called EZ-Kleinprojekte). These funds are split into three different categories called F10, F25 and F50.

F10 offers a maximum fund of 10.000€ and is suitable for smaller and new organisations. F25 comes with 25.000 € and to apply for it, the NGO needs between 1- 3 years of experience.

F50 offers 50.000 € and to apply for it, more than three years of experience with this kind of projects is needed. Also the application for this category is more complex.

All these supports run for one year and a NGO in Germany is mandatory to apply for it. Closer information can be found under www..schmitz-stiftungen.de/de/ezkleinprojektefonds/.

8.2.2 German Embassy in the partner country

Most of the German embassies offer their own funding programs especially for hospitals and technical arrangements. The money can be used for costs for material, staff costs or travelling expenses. The amount differs between the countries and goes up to 15.000 €.

The applications need to be done by NGOs or organisations in the partner couuntry. The embassy in Uganda funds mainly smaller projects with 2.000 - 8.000 € per year. Bigger projects are mainly financed by foundations of the church.

Closer information about NGOs and funds in Uganda can be found here (https://kampala.diplo.de/ugde/themen/weitere-themen/-/1697878?openAccordionId=item-1698288-2-panel).

8.2.3 Innovationsförderung Hessen

The government of the state Hesse in Germany supports especially German NGOs, which are located in the federal state of Hesse. These NGOs have to work in the background of national or international development cooperation and have to support the Sustainable Development Goals.

Projects are supported with 40% of the complete costs. The application can be done any time of the year. A duration of one year for the project is preferred, but a longer duration is also possible. Closer information about the application can be found here: https://www.innovationsfoerderung-hessen.de/epz

8.3 Organizations that are not suitable

- Afrika-Projekt: They are not working together with governments or town councils
- Nord-Süd-Brücken: Only support organisation in the east of Germany with their projects. The Organisation for Western Germany would be Schmitz-Stiftung in chapter 8.2.1
- CLIENT II by the German ministry for education and research: They only support German companies, who are working together with a company in a less developed country
- Worldbank: They only support municipal councils, not town councils like Kayunga. So Kayunga is too small to get this support.

9

Risk Management

It is also important to have a closer look to the risks of this project. A lot of things could happen during planning, installation, maintenance and future using. It is important for the project to keep all these risks in mind and try to avoid them if possible.

- During planning
  - People don´t like the project
  - Miscalculations during the planning process because of missing knowledge
  - Misunderstandings during the planning process
  - Money is missing
  - Needed ground cannot be used
- During realization
  - Components are not delivered in time
  - Not enough manpower for installation available – Mistakes during installation (wrong wiring...)
  - Inadequate hospitality of the project by the local people
  - Price increases during the installation
  - Misuse of the funds
  - Unqualified workers
  - Nobody in the local government feels responsible
- After realization
  - Inadequate follow-up security
  - Batteries and other components are stolen
  - Components are broken earlier because of production mistakes
  - Components are broken earlier because of misusing
  - Poles and lamps are damaged because of accidents or in purpose
  - Cables are damaged or used by inhabitants
  - Components of low quality are replaced before the guarantee by the contractor
  - Nobody in the local government feels responsible

- At end of lifetime
  - No recycling of materials
  - No money available to renew the system
  - Supplier is not on the market any more → New planning is needed – Prices increased and components are not affordable any more.

10

Conclusion

Finally a conclusion about the whole study has to be given which will happen in this chapter.

10.1 Conclusion on system options

There is no perfect solution for a solar street lamp system from our perspective. Nevertheless, we do appreciate both systems depending on their individual strengths. But we should put in mind, that each of them has its own disadvantages.

A centralized system has on one hand a longer system lifespan, it is easier to secure, because all valuable components are at one place and maintenance and system monitoring is easier. On the other hand, there are higher initial costs, the danger of complete blackout, because all lamps are interconnected and supplied from one system and higher planning effort resulting in the complexity of the system. All in all, a centralized system is from a long term perspective probably more stable and easier to maintain. But a lot of expertise in planning and money for funding is necessary in the beginning.

A decentralized system is on one side easier to plan, because of its lower level of complexity, it has lower initial costs and due to the independence of the lamps, there is no danger for a complete blackout after a malfunction or accident. On the other side, frequent battery changes (every 2 – 3 years because of heat load) are necessary and because of the decentralization of the panels, charge controllers and batteries, topics like maintenance, monitoring (e.g. cleaning of the panels) and theft protection are more difficult to solve. Overall a decentralized system is easier to get started with and to expand, because of the lower initial costs and the option to buy easily a small number of lamps. But there is a significant problem with the system lifespan, because of the battery protection, more so against high temperatures.

10.2 Suggestion for future approach

At the end of our investigations we are now aware of the complexity and some challenges that could occur within a realization process. Due to this and in the context of the enormous costs of a complete solar street lamp system for Kayunga, we suggest tentatively an approach, which consists of buying a small number of decentralized solar street lamps and testing them on spots where the whole community of Kayunga would benefit the most.

The sourcing of the lamps should be ideally made from different companies to have the possibility to compare them. Additionally the system behaviour of the lamps should be observed for at least 2 – 3 years. Depending on the experiences and observations within this period, the question if an only centralized based system solution, decentralized solar street lamps or even a mixture of both could be answered more profoundly. During this testing period the community of Kayunga could already benefit from the illumination and in time also new potential funding opportunities for the project may occur.

11
Appendix

The appendix is removed to part 2 of the documentation.

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