Providing Sustainable Life-solutions with a Hybrid Micro-Power Plant in Developing Countries: an Assessment of Potential Applications

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This thesis work is an outcome of an epic journey which has changed my life and my perspective. First of all, I would like to thank to my beloved family for their endless support, and to Gonçal Marion who has been always with me. He has made every single moment much easier and meaningful during this journey. Finally, I would like to dedicate this work to my dearest friend; Mutlu who will never hear about my journey.

Melih
Abstract

Today, energy access is a significant challenge all over the world, particularly in African countries. At the same time, providing energy access is generally accepted as a way to promote sustainable development. In countries such as Uganda, lack of energy access is evident. In this country only 9% of households have access to electricity. About 87% of these households are located in rural and remote areas. Thus, off-grid rural electrification solutions are required to supply electricity services to a significant part of the population.

The ultimate objective of this thesis is to propose a specific solution to cover basic energy needs of the rural population considering environmental, social and economic benefits. How can sustainable life solutions be provided in rural areas, by using the energy surplus from a decentralized small-scale biomass gasification power plant? The analysis used as a starting point the Green Plant Concept, which considers the design of a sustainable off-grid platform that produces energy to provide life solutions and also to excite local entrepreneurship in the rural sites where it is implemented. The concept implies participation of the private sector – a telecommunication company – which is a unique feature in the context of rural energization.

To develop our analysis, a field trip has been conducted in Uganda, Africa, to answer sub-questions such as How to reach a cost-effective system? How to adapt a business oriented approach to the community’s life-style in order to be well accepted? How to foster the development of the area by having a positive socio-economic impact on society? How to create an environmental friendly solution? How to achieve the maximum efficiency in terms of reusing waste? Tools such as Multi Criteria Analysis (MCA) and SWOT analysis were used to interpret collected information and identify impacts of the suggested solutions.

The research has shown the great potential of the Green Plan Concept. We conclude by selecting three applications that can enhance the provision of basic energy needs while creating benefits for the stakeholders involved in the process: i) Mini-Grid solutions, ii) Battery Charging Stations and iii) Heat Pipe Exchangers. We also highlighted the relevance of bringing, in addition to appropriated technologies, different stakeholders together, considering their common interests.

The research is finalized by estimating the payback period based on the current and expected energy consumption and the capital investment related to the suggested applications. It is important to highlight that the payback time estimations do not include the participation of the telecom companies. This means that the estimated payback period of 7 years could be significantly reduced by the inclusion of this stakeholder.

Key words: Energy access; Renewable energy; Decentralized energy supply; Gasification; small-scale power plant; life-solutions.


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Executive Summary

Today, energy access is a significant challenge all over the world, particularly in African countries. At the same time, providing energy access is generally accepted as a way to promote sustainable development. In countries such as Uganda, lack of energy access is evident. In this country only 9% of households have access to electricity. About 87% of these households are located in rural and remote areas. Thus, off-grid rural electrification solutions are required to supply electricity services to a significant part of the population.

This research started as part of a private initiative, led by a Stockholm based start-up company Pamoja Cleantech AB and is concerned with the provision of energy access to rural communities in East Africa. In principle, this initiative is intended to provide electricity by a decentralized energy generation system with concern of all three aspects of sustainability; economy, society and ecology. The business plan includes a telecom booster station for cell-phone communication, which consumption is estimated to be 1 kW with electricity which is provided by a biomass gasification system called The Green Plant (GP) with an expected energy output of 10 kW. The system is expected to use local biomass resources. Our research focuses on how to use the excess electricity in order to provide life-solutions to the local communities. Thus, our analysis is performed in order to identify the potential uses for the electricity and the by-products being generated by the GP.

The ultimate objective of this thesis is to propose a specific solution to cover basic energy needs of the rural population considering environmental, social and economic benefits. How can sustainable life solutions be provided in rural areas, by using the energy surplus from a decentralized small-scale biomass gasification power plant? The analysis used as a starting point the Green Plant Concept, which considers the design of a sustainable off-grid platform that produces energy to provide life solutions and also to excite local entrepreneurship in the rural sites where it is implemented. The concept implies participation of the private sector – a telecommunication company – which is a unique feature in the context of rural energization.

To develop our analysis, an extensive literature review was conducted. Direct observations in the localities Kisiita – Kawoko, Butenga Sub-County, Bukomansimbi County, Masaka District; Sekanyonyi and Nabumbugu Busunju District also provided important evidence to answer sub-questions such as How to reach a cost-effective system? How to adapt a business oriented approach to the community’s life-style in order to be well accepted? How to foster the development of the area by having a positive socio-economic impact on society? How to create an environmental friendly solution? How to achieve the maximum efficiency in terms of reusing waste? Tools such
as Multi Criteria Analysis (MCA) and SWOT analysis were used to interpret collected information and identify impacts of the suggested solutions.

The GP project is formulated in collaboration with, Ugandan Industrial Research Institute (UIRI), The Vi Agroforestry Program, Centre for Research in Energy and Energy Conversation (CREEC) and both Nordic and African universities (Royal Institute of Technology -KTH, Aalto University and Makarere University); along with Pamoja Cleantech AB.

The possible applications have been investigated with the purpose of using the GP with most efficiency and at the same time with the concern of satisfying the communities’ need as much as possible. In order to do so, the authors have always looked for most sustainable way of using the input, output and waste of the system. In this thesis work, the authors have studied seven different applications. All the seven possible applications have discussed and investigated in details in the report. These applications can be listed as follows; 1) Soil Amendment Applications 2) Electrification Applications (Mini-Grid design and Battery Charging Stations) and 3) Waste Heat Applications (Heat Pipe Exchanger, Recuperator, Absorption Chiller and ORC Turbine). The possible applications are analyzed in order to understand if these are feasible or not, from the thesis objective point of view. It is also very relevant to understand that the life-solutions, which are to be covered, are the ones pointed by the community people during the surveys made during the field trip.

The field trips have been organized with the help of the Swedish agricultural NGO Vi-Skogen. The work of the NGO, which is useful for this research, is the transformation of agricultural communities into cooperatives, fostering their development and increasing the yield ratio. Therefore, it is easy for them to highlight areas where the agricultural cooperative could be a good spot for the GP pilot plant, knowing beforehand what the needs of Pamoja Cleantech AB are. In this direction, the sites recommended by Vi-Skogen are: Magala Growers Cooperative and Nabumbugu Coffee Farmers. Then, to start the research, the main points of observation are made in connection to “i) the locality and demographics”, “ii) energy supply assessment, considering the production rate of the village, the main crops, the agricultural residue rate” and “iii) energy demand assessment, considering uses and costs of energy, energy sources, difficulties in energy supply and social needs.

The final decision is to place the pilot plant in Sekanyonyi, which means selecting the Magala Growers Cooperative. This decision has been made by the requirements of the stakeholders and Pamoja AB. One of the main conditions which have been looking for is to have the potential of creating new business opportunities in the village and also to foster the agricultural activities. Magala Growers Cooperative was the most organized community among the others and had a promising social background. The village is
spread along 6 km² with approximately 110 households. The current agricultural production includes maize (140,000 kg/year), coffee (47,000 kg/year), beans (2800 kg/year) and milk (100 liters/day). The energy resources of the area consist of kerosene (lightning purposes), diesel (agricultural purposes), charcoal and firewood (both for cooking purposes). The area covers much of the requirements for the implementation of the pilot-plant. The fact is that the production rate is really high, compared to the other options. Thus, it makes this place the best of the possibilities in terms of feedstock supply and potential of creating new productive activities.

Once the location is decided, the next step is to define the main life-solutions that can be provided to the community, both in the households and the cooperative. The MCDA is the key decision making process of the research. The approach is used in order to compare fairly the different solutions exposed. All the possible applications are analyzed with the MCDA. To apply successfully the method for each solution a spreadsheet table is prepared. The table consists of the potential applications and the criteria related to them (including the weight for each criterion). An overview of the possible market solutions is done to find reliable data of the different applications regarding market issues as the economical costs or the working conditions. The MCDA is the key decision making process of the research. The approach is used in order to compare fairly the different solutions exposed. All the possible applications are analyzed with the MCDA. To apply successfully the method for each solution a spreadsheet table is prepared. The table consists of the potential applications and the criteria related to them (including the weight for each criterion). An overview of the possible market solutions is done to find reliable data of the different applications regarding market issues as the economical costs or the working conditions.

The very final stage of the thesis is to evaluate the functioning of all the applications within the system. The researchers have concluded that the most likely future scenario is one where all these applications, and even others that have not been assessed in this work, are working together, providing different services to a community economically advancing and with a growing potential demand. A hypothesis involving a possible energy demand under specific business relationships, impacts and solutions, is proposed. The results obtained during the research are going to be used in this part, and those are the fundamental basis, the whole work developed is used as an example of how the output of the thesis could work.

To finalize the research an economic assessment has been done, estimating the payback period for the overall system working under two different conditions. In the first case the calculations are done based on the business as usual scenario, which is assuming that the energy consumption trends are kept, thus, the payback time would be about 24 years. This scenario considers that the production rate remains the same and there are no investments on any machinery which would affect the income level. However, the
authors think that this scenario is not likely to happen due to the will to increase productive activities shown by the community during the interviews. Another scenario has been developed based on the electricity tariff defined by Pamoja AB, 0.18 USD/kWh. The expected annual revenue is calculated based on the demanded power of the machinery for the productive activities and the estimated annual consumption in households and community services. The estimated payback time in this case is about 7 years.

Finally, it is important to highlight that the payback time estimations do not include the participation of the telecom companies. This means that payback period would be significantly reduced by the inclusion of this stakeholder.

In terms of achieving a reliable solution and making it sustainable for rural areas in developing countries, project developers need to keep the key life-solutions in mind and design the project to be well accepted by the locals. Hence, the challenge for the GP concept in Uganda is to use a western technology adapted for the locals, according to their needs so that the solution is well accepted by the inhabitants. This final product ensures that these three life-solutions will be well accepted and provide most benefit for the community. The community also needs an increase on the productive activities at the area. The provided life-solutions must cover these need and the business approaches must be accepted by the society. Hence, the final product, which means three chosen life-solutions, ought to work for the community, by the community and also satisfy the economical concerns of the stakeholders.

To summarize, this thesis work shows the challenges that Uganda faces in relation to life-solutions and energy provision. The ultimate goal was to come out with an idea which uses the surplus energy from a decentralized small-scaled power plant in order to provide sustainable life-solutions. We selected three applications that have the potential to achieve this goal, which are; 1) Mini-Grid, 2) Battery Charging Stations and 3) Heat Pipe Exchangers. These three applications address all three aspects of sustainability.

- The research has shown the great potential of the GP project to Pamoja AB. It has highlighted the relevance of bringing different stakeholders together in a most effective way according to their common interests.
- The research also gives a significant importance to the environment and establishes a complete system which ensures to satisfy the economical and environmental concerns at the same time. In this manner, we can all see that it is very possible to achieve a business point which improves the productive activities and financial incomes and still be respectful to the environment.
1. Introduction

Today, energy access is a significant challenge all over the world, particularly in African countries (UN-Energy, 2010). At the same time, providing energy access is generally accepted as a way to promote sustainable development (United Nations Conference on Environment & Development, 1992). In countries such as Uganda, lack of energy access is evident. In this country, only 9% of all households have access to electricity (International Energy Agency, 2011). About 87% of these households are located in rural and remote areas (The World Bank, 2011).

Uganda is a country located in East Africa, which lies on the Nile basin. The lakes Victoria and Kyoga dominate the water resources of the Nile. Nowadays, its estimated population is about 34.6 million inhabitants (Central Intelligence Agency, 2011).

The main electricity supply in the country is based on a large-scale hydropower generation. According to the annual report of the Ministry of Energy and Mineral Development, the total grid electricity supply was 2050 GWh, in 2008 (UMEMD, 2009). The major part of the energy plants operate at Lake Victoria and through the Nile flow, thus are located right outside of Jinja (Busoga sub-region), which is the second commercial hub in the country and located in the south-eastern of Uganda. However, the electricity generation capacity has already been reduced by the decrease of the water level in the Lake Victoria. This fact contributed to a significant increase, from part of the industry, of diesel engines as backup to avoid troubles in case of an electricity shortage (Buchholz & Da Silva, 2010). According to the data on the 2008 annual report of the Ministry of Energy and Mineral Development, the electricity grid consumption was up to 66,426 Kgoe (kilograms of oil equivalent), on the other hand, the amount of diesel fuel reached 96,884 Kgoe (UMEMD, 2009). Nevertheless, the hydropower generation is still the largest growing electricity supply in the energy sector; one of the biggest ongoing projects in the country is the Bujagali Hydro-Power Plant, which will have an output of 250 MW (UMEMD, 2009). In the rural sites, the main energy resource is the firewood and just a limited part of the rural inhabitants is able to use coal and diesel fuel (depending on the family’s income). The dominant energy source (fuel wood) is estimated to make up to 79.1% of the whole energy consumption in the country. Residues (including household and biomass waste) contribute about 4.7%, diesel 4.9%, and grid electricity 1.3% to the national energy consumption (UMEMD, 2011).

This research started as part of a private initiative, led by Pamoja Cleantech AB and is concerned with the provision of energy access to rural communities in Uganda. In principle, this initiative is intended to provide electricity to a telecom booster station for cell-phone communication, which consumption is estimated to be 1 kW. Electricity is provided by a biomass gasification system called The Green Plant (GP) with an expected energy output of 10 kW. The system is expected to use local biomass resources. Thus,
our analysis is performed in order to identify the potential uses for the electricity and the by-products being generated by the GP

The idea is to anchor load customers such as telecom companies to facilitate the provision of sustainable life solutions to the nearby communities promoting local entrepreneurship in the rural sites where it is installed. By sustainable life solutions we mean services and products derived from the excess electricity which is not sold to the telecom company, the waste heat produced by the system and the residues produced by the gasification plant. Considering load-customers implies a better cost-benefit ratio for the project since they can provide constant revenue that would allow maintaining the project.

**Scope and limitations**

This research is developed in Uganda, specifically in the localities Kisiita – Kawoko, Butenga Sub-County, Bukomansimbi County, Masaka District; Sekanyonyi and Nabumbugu Busunju District. The technological solution is limited to off-grid alternatives with focus on biomass gasification.

The research considers the telecom company as an existent consumer. This means that a minimum load already exists for the purpose of dimensioning the project and the needs of the rural communities will be covered based on this initial load.

**Problem description**

Usually, lack of electricity is more evident in rural sites of developing countries. The most common way to access the electricity is to use a diesel generator but this practice only works for private users or companies who have enough resources to purchase the equipment and the fuel. In Uganda, the vast majority of rural population has just the chance to get the electricity by connecting one of the two main isolated networks, set up as a national solution (Buchholz & Da Silva, 2010). It is important to bear in mind that these networks are small and will not reach most of the rural areas in many years (Rural Electrification Agency, 2006). Thus, off-grid rural electrification solutions are required.

Facing up the need for rural electrification issue, the use of the off-grid approach is well accepted globally (The World Blank, 2008).

In Uganda, rural electrification is of great importance and, at the same time, a very difficult task. Especially, it is considerably difficult and complicated when the aim is to achieve a sustainable system that covers environmental, social and economical aspects. In the industrialized countries large-scaled centralized energy plants generate electricity. On the contrary, in the rural electrification case, it is not feasible and efficient to set up such systems. A centralized energy generation plant and a large electricity grid might not be suitable for rural areas, besides the fact that they are not always needed. In fact, it is highly costly and ineffective to choose the large-scale generation approach for places
where the demand and consumption are low. The conflict on the large-scale production comes from the high investment costs that trigger the rise on the electricity tariff for the end user. Furthermore, a low energy demand due to a scant will of pay creates an economical problem for the suppliers (Zerriffi, 2011). Taking into account this situation, off-grid electrification solutions appear as a promising option.

**Objective and research question**

The ultimate objective of this thesis is to propose a specific solution to cover basic energy needs of the rural population in Uganda. *How can sustainable life solutions be provided in rural areas, by using the energy surplus from a decentralized small-scale biomass gasification power plant?*

Sustainable life solutions improve the quality of life and imply reducing the current drawbacks such as electricity shortages, on household or community level. The relevance of this project resides in its potential to cover basic needs of the communities offering at the same time an effective return on the investment which is a unique feature in the context of rural energization. Further, these solutions are based on local renewable energy resources. As a result, they are environmental friendly.

In order to find an answer for the main research question, a number of sub-questions are proposed to guide the analysis. How to reach a cost-effective system? How to adapt a business oriented approach to the community’s life-style in order to be well accepted? How to foster the development of the area by having a positive socio-economic impact on society? How to create an environmental friendly solution? How to achieve the maximum efficiency in terms of reusing waste, cradle-to-cradle approach?

**Methodology**

This work is based on a series of steps that gradually should lead the authors to find the most suitable answer to the research question stated previously. This framework has 5 well-defined stages that can be seen in the Figure 1.

![Figure 1. Methodology](image-url)

In the first phase, the objective was determined and the research questions were formulated. During the second phase, an extensive literature review considering basic concepts, theories and previous research findings provided an understanding of the research context. A field trip provided, in a subsequent stage, evidence in the form of
interviews with local people. Finally, a decision making tool, Multi Criteria Analysis (MCA) was used to interpret collected information and identify potential impact of the suggested solutions. This methodology is described in more detail in Chapter 3.
2. The Green Plant Concept

In this chapter the Green Plant concept (GP) is defined, the most relevant factors involving the boundaries of the project and the stakeholders that have contributed to enrich the work are introduced. Afterwards, an analysis over the potential solutions, applicable under the conditions described previously, will be defined. This description is done in more detail so the constraints of the research are understood, as well as the level of guidance and support received, especially during the field trip in Uganda, from the Pamoja Cleantech AB partners.

2.1 The Green Plant Concept, System Boundaries and Stakeholders

First, is very important to introduce and define the whole concept concerning the GP, what is it and how it works. Thus, the boundaries related to this thesis work are easier to comprehend linking them with the GP development. At the end of this part, the stakeholders collaborating with Pamoja Cleantech AB and with this thesis work are stated.

During this study the authors have been working with a company, which is developing a renewable power generation project, named the Green Plant. The company, as said before, is Pamoja Cleantech AB. It is developing a project based on the design and construction of a modular off-grid small-scale renewable energy system for rural electrification (10kW). The plant is based on biomass gasification, preferably from local agricultural waste. The gasifier and the whole energy production system of the plant are all located inside a shipping container. In this way, a modular structure simplifies the transport and facilitates the installation.

The main goal of the company’s project, the GP, is to design a sustainable off-grid platform that produces energy to provide life solutions and also to excite the local entrepreneurship in the rural sites where it is applied. The main business focus is to anchor load customers such as telecom companies, this load is assumed to be feeding a telecom booster station for cell-phone communication, which consumption is estimated to be 1 kW. Considering these load-customers implies a better cost-benefit ratio for the project, from a profitability point of view, since they would provide constant revenue that would allow maintaining the project. Furthermore, it ensures the fact of reaching into rural communities and creates an opportunity to provide them with life-solutions, this perspective is the one pointed by this thesis work.

The GP project is formulated in collaboration with, Ugandan Industrial Research Institute (UIRI), The Vi Agroforestry Program, Centre for Research in Energy and Energy Conversation (CREEC) and both Nordic and African universities (Royal Institute of Technology -KTH, Aalto University and Makerere University); along with Pamoja
Establishing boundaries within the project helps not to lose track of the main objectives and to focus on the most useful possibilities. In the study case, the boundaries can be divided in different groups. They can be classified as:

- **The Geographical area.** The region in which the solution is being applied would be the surroundings of the plant, the community who lives and works within this region. This means focusing in the local problems.

- **The Use of residual energy and waste of the main plant as input.** The main available supply for the final product would be the waste of the plant itself and/or the non-used energy. Thus, the final product should be limited to that input not creating a need of new supply lines.

- **The Cost.** It is meant to be a sustainable solution; the investment should not exceed a reasonable cost. That means that the capital investment must not mean a significant change in the main budget of the company.

- **The Population needs.** The proposed solutions will be only those that are useful for the population and those that can mean a positive impact on the area to foster the economical development. That implies focusing on the real and current problems that stop the rural progress.

- **The Space in the container as technical/design constraint.** As the system has to be transported inside the container, the limitation of space inside will suppose a major restriction regarding to practical solutions and the design phase.

- **The collaboration between Pamoja and the telecom company** is out of the system boundaries. The only issue that has been taken into account is the constant energy supply to the telecom tower and it is estimated to be 1kW.

- **The limited knowledge about the technology used in the gasification process.** Pamoja Cleantech AB is still developing the system that will drive the gasification process, and so, limited data is available regarding the waste thermal heat obtainable.

- **The use of Multi-Criteria Decision Analysis (MCDA) as a discarding tool.** The MCDA is not used as a deep analysis process but as a method followed to discard the less efficient solutions and from then, continue with a more detailed approach to the ones that performed more successfully.

- **The assumptions made during the research.** Throughout the different analysis performed, mainly in the results part, assumptions have to be made when data is not at researcher’s disposal. It slightly reduces the reliability of the project, but is the only option to continue with work. Those assumptions are always made in base of a reasoned judgment.

- **The use of the some procedure as example instead of exact data.** The above-mentioned fact about the shortage of concreteness, suggests using some of the procedures, the ones where more assumptions are made, as examples of
how the development of those parts must be done instead of a source of exact data.

As it can be seen, the Figure 2 describes the GP and its relation with the stakeholders linked to the boundaries described previously. It includes the basic functions such as the energy input and output and the additional applications. Apart of these functions, the stakeholders that are working with Pamoja Cleantech AB are included in the diagram too.

These partners collaborate in order to set up a successful business model, to provide technical support, to help find possible pilot areas where to test the system and to promote the idea within community as well as with the institutions. A brief description of each of them is given below:

- **Community.** The social web is the main stakeholder of this thesis work. The whole research is based on community’s necessities and development. The community is the customer who is taking advantage of the output of the thesis in form of life-solutions. The communities visited include the Magala Growers and the Nabumbugu Coffee farmers Cooperative in the Busunju area, and the Esukanesi Memorial Primary School in Nyendo, Masaka area.

- **Vi-Skogen (The Vi Agroforestry Program).** Vi-Skogen is a Swedish Non-Governmental Organization with the headquarters in Stockholm. The program runs six small-scale farming projects around Lake Victoria; two in Kenya, one in Uganda, two in Tanzania and one in Rwanda. These projects aim to prevent soil erosion, produce fuel-wood, timber, and fruits, to generate income and improve the environment. Nowadays, they are working with around 150,000 families (more than 1 million people) and, every year small-scale farmers grow over ten millions trees. Vi-Skogen is the link between the agricultural cooperatives and the research group, helping to arrange the supply chain and business model between the community and Pamoja Cleantech AB. In addition, the collaboration leads to find the selected community for the pilot plant project. Regarding to the thesis work, the main support from this organization has been focused in the data collection and the surveys management during the field trip.

- **Agricultural Cooperative.** It is the part of the community dedicated to the agricultural production. And so, is supposed to be an important stakeholder to the thesis project as it should be one of the main users, as productive activities most probably need a source of electricity to improve and to become more efficient and sustainable.

- **CREEC.** It is a research institution that is founded under the Office of the Dean of the Faculty of Technology, Makerere University in Kampala. The aim of the institution is to be the bridge between researchers, scientists, business community, funding agencies and the general public. Mainly, the purpose of the
organization is to support pilot projects. To do that, they provide technology, any implementation requirement and training studies. In addition, they increase the public awareness and participation. One of the most important aims of CREEC is to work on rural electrification systems. CREEC has stated this aim as to carry out research and feasibility studies on renewable energy system such as hybrid systems to power rural communities, set-up of mini-hydro, and biomass use for power generation, affordable ways of extending the national grid, Solar Home System innovation and design, etc. Regarding to the project, CREEC provided technical support, experience in the field and some funding for the GP development. The advising provided to the researcher of this work has been dedicated to the potential solutions assessed as the energy recovery systems.

- Telecom Company. It is the main load-customer for the GP concept, the basis for Pamoja Cleantech AB’s business model. In relation with the thesis work is just important to remember that the booster station tower has a load of 1 kW, and so, this power will not be available for a life-solution use.

![Figure 2. System boundaries and Stakeholders Overview](image_url)

### 2.2 The Green Plant and the Potential Applications

The following part is firstly introducing the link between the green plant and the thesis project. It is stating the principal concepts within the system; see Figure 3. Then, separated in different headlines, the potential solutions are described and analyzed in order to know which the possible outputs of the project are.

It is already stated how the GP works and the first purposes of Pamoja Cleantech AB. And so, once the initial business concept of the company is known, the thesis framework concept has to be introduced. At the same time the thesis work started, the company began to study various potential sites, where the pilot plant could be placed, as well as
working on different design approaches. These approaches consider the electricity surplus and other by-products that could be used according to the specific needs in the area of operation. In that direction, and as declared previously (section 1 Introduction), the ultimate goal of the thesis work is to identify further potential uses for the electricity and by-products\(^1\) being generated by the Green Plant and to formulate a sustainable solution in terms of economy, environment and social impacts. It is crucial to identify the most important applications of this surplus energy in order to turn it into a meaningful contribution to the rural zone.

As a first approach, Figure 3 is made in order to understand the general concept. As it can be easily seen in the schema, the overall process is divided in 5 parts, each of them defining a level through the whole energy stream. Starting from the raw material, passing through the conversion of this material into energy by the gasification process, and finally, the core of the thesis: analyzing the potential energy forms; how can these be converted into a useful way of energy, thus, approach the main human benefits that can be provided with them.

It is important to understand that the mentioned “Potential Applications”, in the Figure 3, are the solutions that will be analyzed in the following points of the thesis in order to understand if these are feasible or not, from the thesis objective point of view. It is also very relevant to understand that the life-solutions, which are to be covered, are the ones pointed by the community people during the surveys made during the field trip; this will be explained in further sections. As said previously, a deeper analysis and understanding of the “Potential Applications” is done in the following part.

Finally, in the same direction of what is explained in the previous paragraph, is important not to confuse the “Energy Carriers” concept with the “Potential Applications” and the “Life-solutions” definitions. The “Energy Carriers” are the direct output of the GP, and what has the energy potential that can be used. The “Potential Applications” are the practices that transform this energy in something applicable in the selected location. And so, be able to cover the “Life-solutions” lacking in the local community.

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\(^1\) By-products include energy sources as, exhaust gas or waste heat or the biochar as a system output.
<table>
<thead>
<tr>
<th>Local Resources</th>
<th>Conversion Technology</th>
<th>Energy Carriers</th>
<th>Potential Applications</th>
<th>Life-Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Waste</td>
<td>Soil Amendment</td>
<td>Soil Amendment</td>
<td>Agricultural Profitability</td>
<td></td>
</tr>
<tr>
<td>Waste Heat</td>
<td>Heat Pipe Exchanger Recuperator Absorption Chiller ORC Turbine</td>
<td>Coffee Drying Milk Storage Milling Shaft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>Mini-Grid Battery Charging Station</td>
<td>Lighting Battery Charging Refrigeration Beauty Salon Health Care</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 3. Energy Development, from Raw Material to Life-Solutions*
2.2.1 Biochar Application

As it has been stated in previous sections, the proposed solution should consider a cradle-to-cradle approach, amongst the other objectives. Hence, the solid waste of the GP ought to be reused or transformed into another profitable form. The gasifier produces charcoal-like solid material, which is also called biochar. The procedure followed for the biochar production is to heat any kind of biomass in the absence of oxygen for a specific time (between 350 and 600°C) (McLaughlin, et al., 2009). This process is called pyrolysis and it results in a carbon rich product, and what is more important, its carbon compounds results to be highly stable. Thus, it provides highly efficient storage of the carbon (Lehmann & Joseph, 2009).

There are still several discussions going on about the biochar production issue. However, there are not many scientific reports about this topic. The discussions are mainly focus on the biochar production technology. These are directly related to the gasification system whether it is a downdraft or updraft gasifier. And, as the exact technology that is going to be used by the GP is yet unknown for this research, this dilemma is not taken into consideration (Brown, R.C., n.d.).

The most significant background of the biochar application is derived from the Amazonian rainforests findings (AKA Terra Preta) (McLaughlin, et al., 2009). Several studies have shown that biochar highly exists in the soil of the agricultural areas that are very productive and have a great yield (Lehmann & Joseph, 2009). On the other hand, it is rather difficult to give a sharp opinion about the cause and effects of biochar within the modern agricultural applications, even though the modern way of thinking tries to find opportunities of replacing chemical-based fertilizers of the industrialized agriculture (McLaughlin, et al., 2009).

Nowadays, one of the most important known benefits of the biochar is its potential of GHGs mitigation due to its long-term carbon storage capacity (McLaughlin, et al., 2009). Despite, recent researches are mainly focused on the results of applying biochar to soil in terms of the management of agriculture and environment. An important fundamental book on biochar and its applications is “Biochar for Environmental Management” which is edited by Lehmann and Joseph (2009). The authors have described the purpose of applying biochar to soil by the following categories:

- Agricultural profitability.
- Management of pollution and eutrophication risk to the environment.
- Restoration of degraded land.
- Sequestration of carbon from the atmosphere.

**Agricultural profitability**
As mentioned before, published studies and current applications are rarely found on this topic. In the “Biochar for Environmental Management” book, are given some examples about biochar application in crop productivity (Lehmann & Joseph, 2009). In this case
study, agricultural profitability covers both economical feasibility and crop productivity. The key point of the literature review on biochar application, which must be taken into account during this thesis project, is that those entire examples are from tropical climates, as well as Uganda (U.S. Department of State, 2011). Although, some of the effects can be listed as below:

- Increased root nodule formation, plant growth and yield.
- Increased N fixation.
- Decreased amount of requested fertilizers and chemicals.
- Increase of biomass.

However, in order to be economically feasible, the biochar application should have lower production costs than the improved agricultural products. Since there is lack of research on biochar productivity, it becomes even more difficult to find information about its profitability. One of the studies on the topic, which is done by Galinato et al. (2010), is about wheat farm profitability with and without biochar in Washington State. In the study, the authors have estimated costs and returns for using biochar as soil amendment. The methodology used has been to assess the reduced emissions of using biochar, and also accounting the benefits of the carbon sequestration after its application. In addition, a comparison has been performed between the productivity after the biochar application and after the lime application to the soil. The conclusion part of the mentioned research is focused on quantifying all the possible biochar applications to soil, they come up with the idea that the biochar can be economically feasible only if:

- The farms can justify the carbon sequestration on the carbon market and get promoted by authorities.
- The biochar market prices are low enough.

**Soil Management and Carbon Sequestration**

Agricultural profitability is one of the promising impacts of using biochar as fertilizer; furthermore another important issue is the carbon sequestration. National Sustainable Agriculture Information Service (ATTRA) (Schahczenski J., 2009) has published a broad study on carbon sequestration where it has been looking for the relationship between agriculture, climate change and carbon sequestration.

Carbon sequestration could be simply defined as removing carbon dioxide from atmosphere by agricultural fields. In the natural carbon cycle, during the growing of plants, CO$_2$ is absorbed from the atmosphere and afterwards when plants die, during the decomposing of organic substances, CO$_2$ is emitted to the atmosphere again. Hence, the overall natural cycle is carbon neutral (Schahczenski J., & Hill, H., 2009). The problem with fossil fuels in terms of global warming comes up at this moment. Fossil fuels add more carbon to the atmosphere as they are burnt. In contrast, pyrolysis can detain this atmospheric carbon as biochar for long periods and by biochar application, this carbon can be stored in the soil. Therefore, the biochar approach is an attractive solution to cope with global warming concerns (Lehmann & Joseph, 2009).
As explained, soil has a huge potential to store carbon and it is already the biggest carbon-carrier. Biochar is helpful to increase this potential and by doing so, it is a soil protection and maintenance (Schahczenski J., 2010), at the same time and, as it has been mentioned in the previous paragraph, this situation makes biochar important in terms of carbon trading value.

Taking advantage of biochar potential of boosting soil with organic carbon, increasing nutrient retention and improving crop productivity could be the most important approach in order to achieve local sustainable development (Whitman & Lehmann, 2009). Biochar applications are getting more interest in Africa. According to a group of African nations and UN Convention to Combat Desertification (UNCDD), the biochar applications could be the next key method to cope with global warming (Whitman & Lehmann, 2009). Besides, the soil amendment application is not only an opportunity to add positive value to the GP, but also to develop a sustainable agriculture system. This application would increase the productivity of the farms and put the agricultural residues to use. Working closer to biomass sources and with the local communal groups where the GP is located could also be a very important chance to accelerate the rural economic development.

2.2.2 Electricity Supply

There are numerous projects, applied and ongoing, which are concentrated on rural electrification in different parts of the planet. The researchers have observed that the main differences between the options applied are founded on the way the energy is generated. For instance, the projects are mainly based on solar, wind and biomass energy production. Therefore, since Pamoja Cleantech AB’s main project is aimed to produce electricity by gasification, the researchers have decided to examine just the electricity network options rather than the generation technology itself. In this case, the main options are mini-grid systems and battery charging systems in order to reach the end user.

The aim of this application is to run the Green Plant with the objective of providing a more reliable and economical source of energy to the rural inhabitants and help to reach a local sustainable development. By doing so, productive activities could be increased in the area; the locals could get benefit from the light, life-solutions and other demands of the community, in which the GP will be located. And as mentioned in the previous paragraph, two systems are to be analysed, the mini-grid and the battery charging system.

**Mini-Grid**

There are different ways of establishing an off-grid system as a rural electrification method. The decision is usually made based on values as the energy consumption, the average income and the willingness to pay amongst the community. The electricity generating systems that are mainly used consist of diesel generators, micro-hydropower plants and renewable energy technologies. The most common renewable energy
solutions for the off-grid electrification are either solar or wind power. The biomass-based power plants are rarely used for this purpose (World Bank, 2008).

The mini-grid might be the most crucial one amongst all the other application that are considered in this thesis project. The reason is that the mini-grid is supposed to increase the life condition of the community but at the same time with its high potential of boosting the productive activities, the system is expected to empower the economical and social development of the community.

In 2002, The World Bank, performed a research on the socio-economic benefits reached out of a rural electrification project in Philippines (The World Bank, 2008). Some of the results are given below; see Table 1.

Table 1. Socio-Economic Benefits of Rural Electrification in Philippines (The World Bank, 2008)

<table>
<thead>
<tr>
<th>Benefit Category</th>
<th>Benefit Value (US$/month)</th>
<th>Consumer Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less expensive and expanded use of lightning</td>
<td>36.75</td>
<td>Household</td>
</tr>
<tr>
<td>Less expensive and expanded use of radio and TV</td>
<td>19.60</td>
<td>Household</td>
</tr>
<tr>
<td>Improved returns on education and wage income</td>
<td>37.07</td>
<td>Wage earner</td>
</tr>
<tr>
<td>Time saving for household chores</td>
<td>24.50</td>
<td>Household</td>
</tr>
<tr>
<td>Improved productivity of home business</td>
<td>34.00 (before mini-grid)</td>
<td>Business</td>
</tr>
<tr>
<td></td>
<td>75.00 (after mini-grid)</td>
<td></td>
</tr>
</tbody>
</table>

The data in Table 1 shows how the economical level of the households and the local businesses, after the implementation of the project, rise up. It is remarkable that the productivity of home business almost doubled after the connection to the electricity grid.

Finally, in order to make the system’s explanation more understandable, the Figure 4 is a conceptual schema of how the mini-grid should be. Basically, in the system, the GP provides the produced electricity directly to the booster station tower and the community. Besides, at the same time, the system contains a battery charging system that provides electricity to the community during the low generation period as a back-up system. The main components of the back-up system are the batteries, which are charged by the GP output. The inverter reverts the alternative current network into direct current to charge the batteries. Thus, under the demanding time, the grid electricity will be fed by this stored energy. The specification and detail of the data is subjected to the agreement between the researchers and Pamoja Cleantech AB to protect the privacy of the project.
As a last clarification, it is important to see that the battery system included in the mini-grid design, see Figure 4, is different and independent from the battery charging system explained below. The both of them could coexist in a hypothetical scenario.

**Battery Charging System (BCS)**

The battery charging concept is designed and developed for the rural areas where the national electricity grid is not established and also not likely to reach in the near future. The targeted users are low-income groups who cannot afford to purchase diesel generators (or any other energy resource e.g. solar panels). The BCSs are more efficient for those locations where there is a low energy demand. The capacity of the system is flexible and can be designed according to the number of users and their electricity needs (Zerriffi, 2011). Basically, the system includes a battery charger located nearby the energy resource and several batteries.

An example of the application of this system in Vietnam can be found in the paper that is published by Dung et al. (2003). In Vietnam there are 30 BCSs that were installed in 1990s, in which the energy source comes from photovoltaic solar panels. One singular case from the paper was based in a village where nearly 600 families (population of 3000 inhabitants) were living. The project was designed to electrify houses, the post office, the health centre and a cultural room. Since it would not be possible for the inhabitants to own solar panels in individual base at home, the charging station was established to decrease the initial cost for local community. The BCSs were usually installed at a common site and trained personnel were taking care of its maintenance.

A useful method that can be extracted from this work is that there was a criteria followed in order to decide about the better placement for the BCSs, potential places where the system could be leading a positive impact. The given considered conditions in the report for starting the installation are listed as:

- Placement of the station and users locations according to the BCS
• Willing of pay and economical conditions of the locals
• Potential of the site would have the grid electricity connection
• Energy resource alternatives
• Electricity requirements, e.g. for lighting, education, entertainment, milling, water pumping etc.
• Local cooperation

This methodology was helpful to establish the research work. Besides, an important given figure in the Vietnam case study was the method of choosing right battery type for the project. Following that, it is clear that depending on the activities carried out in the household, regarding to the level of the consumption, the battery should be different, see Table 2. And so, having an overview of what are society the needs and its consumption is basic to determinate which battery system will be used.

Table 2. Appliances of the BCS in Vietnam (Dung, et al., 2003)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Energy Demand</th>
<th>Operating Hours</th>
<th>Capacity of Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Only lighting</td>
<td>3-4 h</td>
<td>20 Ah</td>
</tr>
<tr>
<td>2</td>
<td>Lighting and B&amp;W TV</td>
<td>Lighting: 1-2 h and TV: 3 h</td>
<td>25-30 Ah</td>
</tr>
<tr>
<td>3</td>
<td>Lighting and color TV</td>
<td>Lighting: 1-2 h and TV: 2 h</td>
<td>70 Ah</td>
</tr>
<tr>
<td>4</td>
<td>Lighting, color TV and VCR</td>
<td>Lighting: 1-2 h and TV &amp; video: 2-3 h</td>
<td>100 Ah</td>
</tr>
</tbody>
</table>

The Rural Electrification (Zerriffi, 2011) textbook contains several different off-grid electrification cases in Brazil, Cambodia and China. The conclusion that can be taken out of these different studies is that the life span and success of the project is defined mostly based on the economical conditions of the area and the performance of the system. In order to financially maintain a project, the throughput should be maximized, which means that the stakeholders must ensure that the utilization capacity is being used as much as possible. The willing of pay is one of the most important constraints of this project, and in that matter, creating new business for the farmers and ensuring the power demand is of great importance; for example, new water pumping system and the irrigation could increase the yield of the crops (Ravindranath et al., 2006).

2.2.3 Waste Heat Recovery

In this section are explained the possible heat recovery systems. One of the major restrictions of the project is to take advantage of the surplus of energy. In specific case, this energy usually appears as a waste, despite of this drawback, it and has a great potential when it is transformed into the appropriate form. It is just relevant to state, regarding the thermal energy, that the gasification process and the engine are the main
contributors (U.S. Department of Energy, 2005; Pandiyarajan et. al., 2010) as sources due to the combustions carried out during the different energy production stages. To that point, add as well the fact that the whole system is located inside a closed container, and as a result of that, the thermal energy is concentrated, so it should be easier to accumulate.

The possibilities of recovery and use of heat energy are vast. The different options that this energy source can offer are varied and mainly depend on the energy source, its quality and quantity. Also, the way to gather and stream the heat depends on the purpose of use; obviously it is not the same process if the aim is to produce cooling for a refrigerator as if it is to supply mechanical power to a shaft for agricultural systems. And so, as there are many systems that could be implemented and it would take a long time to describe in detail all of them, the analysis has been done about the most relevant and likely solutions for heat waste recovery/reuse.

The main issue within this topic is to be able to recover all that waste energy in the most efficient way; so, the less quantity is lost in this procedure. In order to convert this heat into a useful energy stream it is recommended to use the system that better performs under the working conditions; that is referred to the characteristics of the system and the heat. It is also important to understand the contribution each system can bring to the community, so, the devices analysed below have been classified in three groups depending on the objective they cover. The groups are: heating system, cooling service and mechanical power.

**Heating system**

The devices described in this group are the ones that are using the waste thermal energy to apply it as heat for a specific purpose, e.g. seed drying. Thus, there is no further process than the fluid-to-fluid heat transfer.

- **Heat Pipe**

  The heat pipe consists in a sealed pipe or tube closed in both sides, in which inside there is a fluid. The kind of fluid depends on the characteristics of the system, temperature and pressure. The pressure can as well be modified so the fluid works in the rank of temperature desired. In the inside of the pipe there is as well a capillary wick that separates the gas from the liquid phase of the fluid. All the inner space of the pipe remains in vacuum condition. Once the components of the system have been described the process ongoing during the heat exchange can be easily interpreted by the following picture, see Figure 5.
The functioning of the heat pipe is very simple. Shortly, the heat absorbed by one side of the pipe is transferred to the other side and released. Once the heat is released it is possible to use it for heating other fluid or, for example, to heat a chamber in which the crops could be drought. Some of the advantages this system provides are that there is the no need of energy input, and its maintenance it is considered low because it does not have any mechanical parts that are constantly moving or any part that can wear out. (Bureau of Energy Efficiency, 199?)

- **Recuperators**
  The recuperators work normally with the exhaust gases of the engines, pre-heating the air that has to work in the combustion chamber. It can also be applied in other cases; mainly it is air-to-air or air-to-fluid heating transfer. For the case under study this system is interesting because of many reasons but one really important it’s its simplicity. In the picture below, see Figure 6, it is outlined the basic working process of a convective recuperator; the heated fluid is air. As it can be easily seen in the Figure 6, the air that is heated is the one running inside the tubes, the exhaust gas used is introduced in the shell, and cooled down as it transfer the thermal energy to the air.

This kind of system is commonly used, as well as in air pre-heating, in air-conditioning or ventilation of big spaces (Bureau of Energy Efficiency, 199?).

**Cooling service**
The transformation of heat into a cooling source can be a very useful tool. It is likely to find facilities, in the area where the GP is applied, that need the supply of a cooling
service for their functioning; e.g. health care clinics, schools, offices or grocery stores.
The most promising system for this task is the absorption chiller.

- **Absorption Chiller**
The conversion from a thermal to a cooling source of energy performed by the absorption chiller is characterised for the almost negligible input of electricity that it demands. The main energy feeding of the system is the waste heat recovered. There are just two pumps that have to be connected to electricity, although the consumption is below the 1% of their cooling capacity (Trane Company, 1989 cited in Gordon & Choon, 1995). The technical aspects of this device are explained in the Appendix I.

**Mechanical Power**
The machinery used in most of the agricultural processes, as mills or coffee husk separators, work under a mechanical shaft. The Diesel generators are the main supply source of this power, and as said before, not everybody is able to access it. Providing a mechanical shaft by the reuse of waste energy appears, at first sight, as a potential cheap possibility to contribute to the improvement of the productive activities in the surrounding area of the GP. Thus, the system that better fulfils these requirements is the Organic Rankine Cycle turbine (ORC).

- **ORC turbine**
First of all it is important to state that this device is still under development, although it is not difficult to find or purchase in the market, the characteristics and specifications and working conditions are tightly subjected to the manufacturer and its advising. In the Appendix II is it possible to find a detailed description of the system.

The ORC turbine system is specifically designed to reuse the waste heat produced during combustion or in other energy-to-power processes. The ORC turbines can work within a range of temperatures, for the waste heat recovered, from 60 °C to 200 °C (Yamamoto, et al., 2001). The fact that it is really hard to improve the efficiency of the current combustion systems, or all the processes in which the lost of heat is involved, is a significantly important factor that motivates the research on this system (Hung, et. al., 1997)

As a final analysis of the ORC turbine, the advantages and weaknesses of the system are described below, as strong facts:
- The performance of the Organic Rankine Cycle (ORC) shows a low maintenance cost and a high safety grade on converting the waste heat into a useful and profitable energy source (Wei, et al., 2007).
- The “value” and the feasibility of this system increase in regions where the fuel price is high. (Hung, et al., 1997).
- The technology that has to be implemented is simple, occupies a reduced space due to its small size and the non-emission of GHG or other pollutants turns the system into environmental-friendly. (Yamamoto, et al., 2001).
On the other hand, the main problem to overcome is:
- The thermal efficiency of the Rankine cycle decreases as the temperature grade of the fluid gets low.

As a final conclusion for this overall section, remark that the evaluation of the GP project, the stakeholders and the thesis work boundaries together with the review of the analysed solutions, provides with a useful feedback and an overall view necessary to successfully continue with a deeper analysis and a better understanding of the whole system.
3. Methodology

In this chapter, the methodology used to develop the thesis project is explained. The chapter is intended to guide the reader through the research path followed by the authors. The diagram in Figure 7 shows this research path and links it to the structure of the thesis; it also contains a brief explanation of each step taken during the research.
Research Question
How can we provide sustainable life solutions in rural areas, by using the energy surplus from a decentralized small-scale biomass gasification power plant?

Literature Review
Institutional & Scientific Sources
- The background of Uganda as well as the energy situation is studied in this part (1. Introduction).
- The institutional sources, which are provided by Pamoja Cleantech AB, are used to give an overview of the whole system, including the technical framework and the stakeholders (2. The Green Plant Concept).
- The scientific sources are used to cover an overview of the current energy situation, possible applications, and sustainable energy management in developing countries (2.2 The Green Plant and the Potential Applications).

Field Study – Collecting Data
- The description of the approach to the site visits (4.1 Site Visit Preparation).
- The results of the surveys used to illuminate the relevant data (4.2 Survey of Visited Sites).

Analyzing and Interpreting Data
- The Selection of the site for the implementation of the pilot plant is done following the data grouped from Table 5 to Table 9 (4.3 Pilot Area).
- The next step is to identify the potential benefits that can be provided to the community. The benefits are studied based on communal and productive energy uses. The results are shown as the possible applications and the life-solutions each would provide, see Table 10 and Table 11 (4.4 Applications and Life-solutions).

Results
- At this point of the research, the pilot site and the life-solutions that could be provided by each application are known; so, the selection process starts. After applying the MCDA the most promising applications are selected to the final development (5.1 Selection of Possible Solutions – MCDA).
- Once the selection is performed the potential impacts and the SWOT are done for the selected applications (5.2 Potential Impact Identification of the Selected Solutions).
- Finally, as a conclusion of the research, a final view of the applications is given as a budget and a concept modeling. In this section, instead of analyzing each solution separately, the intention is to merge the applications and evaluate them as a system. This last view includes an assessment of how the system works and interacts with the different members of the community (5.3 Final View of the Product).
The starting point of this work is the statement of a research question. The second step of the research consisted of performing a literature review with the aim of building an overview of the current energy situation and sustainable energy management in Uganda, a description of the whole system including the technical framework of the project and its stakeholders; and finally an assessment of the possible solutions to be applied in order to respond to the research question. The literature review included the examination of scientific publications, development agencies’ reports, product brochures, etc. Internal documentation at Pamoja Cleantech AB was particularly important to describe the system and the stakeholders involved.

The next step of the work consisted of observations and interviews. This step was developed in Uganda. The observations and interviews were conducted during a 2-month field trip that included visits to different institutional centers as UIRI (Uganda Industrial Research Institute), Makerere University and Vi-Skogen facilities amongst the most important; also areas to be evaluated as pilot sites including Sekanyonyi and Nabumbugu Coffee Farmers cooperative in the Busunju area. The fieldwork is an important part of the case study because it increases the reliability of the research and the report itself. The fieldwork covers both, the socio-economical and the physical conditions of the selected villages. During the development of the data collection process, in the visited locations and during the surveys, a number of interviews are done to easily retain the most useful information. The interviews are tape-recorded and written down into word processing software in order to make the information much more accessible and easier to analyze. Also, this method was useful to keep on retaining the possible applications and the actual conditions of the villages. The most relevant information from each interview was taken and considered as powerful input to the new product of the system.

The aim of the site visits was to choose a place where there were favorable conditions to foster the objectives of the research. The intention is to find an undeveloped village with a significant energy demand and a potential of creating new business opportunities. Thus, connecting these site conditions with the main goal of providing as much life-solutions as possible. Furthermore, the physical and structural conditions of the area were also taken in account. In that direction, the focus was on villages that are neither connected to the national grid nor planning to be connected in a long time, according to the Ugandan Rural Electrification Agency (2006). Moreover, the interest in the current situation of the telecom company is considered as a requirement for Pamoja Cleantech AB, due to the fact that its primary business model is linked with the energy supply to the booster stations.

Regarding the potential places where the Green Plant could be installed, the authors designed a specification sheet, which is included in Appendix III. In the same direction, there is a list with various requirements and its importance regarding to the aim of the project. This list is used during the field trip, by the researchers and members of a Pamoja Cleantech AB team, to assess the suitability for the project of different visited
places; see Table 3.

**Table 3. Requirements for the Site Visits**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Level of requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good accessibility</td>
<td>Min</td>
</tr>
<tr>
<td>Existing local businesses with a need of electricity</td>
<td>Must</td>
</tr>
<tr>
<td>Second key customer on site (hospital, hotel, farm, etc.)</td>
<td>Min</td>
</tr>
<tr>
<td>Off-grid village/town</td>
<td>Must</td>
</tr>
<tr>
<td>Potential new site for telecom base station</td>
<td>Min</td>
</tr>
<tr>
<td>Existing mobile base station with diesel generator and the interest in our system</td>
<td>Min</td>
</tr>
<tr>
<td>Available biomass either not-used biomass waste (saw dust, nutshell, rice husk, wood waste, bagasse,...) or existing biomass fuel production.</td>
<td>Min</td>
</tr>
<tr>
<td>Land available for local biomass production</td>
<td>Wish</td>
</tr>
<tr>
<td>Not far away from Kampala</td>
<td>Wish</td>
</tr>
<tr>
<td>Existing forestry program</td>
<td>Wish</td>
</tr>
<tr>
<td>Already an existing development hub of other organisations (e.g. Millennium village, etc.)</td>
<td>Wish</td>
</tr>
</tbody>
</table>

As a result of literature review, observations and interviews, the pilot project area was defined and the needs of the society were characterized. The potential areas were deducted from the interviewees’ opinions about the current situation of the village. Hence, the authors have pooled literature review, observations and interviews. It is also relevant to state that the work done during the literature review helps to be more efficient in the field trips; it allows the researchers to have a better understanding of the actual possibilities of energy use in developing countries, of what had been applied or not, and it delimits the survey investigations to specific characteristics and elements that are pointed by the researchers, in base to the previously acquired knowledge.

Subsequently, the collected data is analyzed with the purpose of answering the research sub-questions, which are given in the introduction part. This analysis is performed by the use of Multi-criteria Decision Analysis (MCDA), which helped the systematization and analysis of the collected information. First of all, the data is grouped according to its relevance. Then, all the potential applications and results of the field trip are combined and analyzed together with the intention of providing potential solutions to decision makers. Hence, the output of the analysis is the selection of the best potential applications that are to shape the final solution of the thesis work. It is important to remark the fact that, in this study case, the MCDA is not used as a deep analysis process but as a method followed to discard the less efficient solutions and from then, continue with a more detailed approach.

The feedback that the researchers get after these analyses helps to do a more exact design of the whole system. And in that direction, the researchers, as final output, can set up a likely scenario with the selected applications working together as a unique system.
The diagram described in the Figure 8 summarizes the methodology explained in previous paragraphs. The stages of the research are indicated in the flow and the lists contain the outcomes of each step, which will be discussed in chapters 4 and 5. Sequentially, the conclusion of one stage is used in order to perform the following step.

![Diagram](image)

**Figure 8. Main Research Stages and Outputs**
3.1 Selection of Possible Solutions – Multi-Criteria Decision Analysis

The ultimate objective of this very specific section of the work is to analyze the different exposed solutions, compare them according to criteria, which at the same time are related to the research sub-questions, and rank the mentioned solutions depending on their grade of performance related to these criteria. After these procedures the selected solutions will be defined, as systems or products, for a further and deeper assessment and design.

The literature review done reveals a variety of solutions that could be applied as an output of the research project. Hence, to narrow down these different possibilities, discarding the inapplicable and the non-efficient regarding to the specifications defined by research sub-questions, there are a variety of methodologies that can be applied in order to help taking a wise judgment, founded in several bases which give to the decision a logical justification, and which in essence represent a significant aid to the decision-makers (DMs).

There is a fact that should not be forgotten which affects the performance of this analysis. It is the reduced knowledge about the GP potential regarding the energy waste recovery, because the specific gasification system that is going to be used has not been defined yet; and due to the limited information related to the working specifications of the different solutions stated previously. Despite the lack of exact data, the analysis is carried out applying in all the decisions the useful knowledge and experience gathered during the field trip, the first steps of the literature review and after the advising of the various stakeholders involved in the project. It is also important to point the fact that this is a preliminary analysis, mainly used to discard inapplicable options, not aimed to define the output of the project.

There are several systems and methods created for that aim, but in the case under study it has been understood that the most suitable procedure would be the appliance of the multi-criteria decision analysis (MCDA) (kiker, et al, 2005). The MCDA is chosen because it considers the participation of different stakeholders (researchers, companies, society, etc.) involved in a project, as well as the different solutions that must be assessed depending on the research sub-questions to be answered (kiker, et al, 2005; Guitouni & Martel, 1998; Triantaphyllou, 2000).

Once the application of MCDA has been decided, different MCDA methodologies must be assessed according to the purpose of the DM and the particular conditions of the study. There are several scientific papers, which offer some aid to choose the best MCDA; those are based on the characteristics of each MCDA method and the objective of the DMs (Guitouni & Martel, 1998). In this particular case, considering the characteristic of the study and the existent solutions, the selected methodology is the Weighted Product Model (WPM).

Finally, the utilization of the WPM is based on the aim of finding which are the best
solutions, amongst the described in section 2, regarding to the research sub-questions. That is, selecting the ones that maximize the sustainability in terms of economical, social and environmental development.

**Weighted Product Model (WPM)**

The WPM methodology is complex and needs a long explanation to achieve a good understanding of the whole process. Thus, a brief but useful description of the most important concepts is done below. In order to get a deeper approach see Appendix IV.

As it has been described by Triantaphyllou, et al. (1998, p. 5):

“In WMP each alternative is compared to the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion.”

In the schema below, see Figure 9, it is described, in simple terms, the process carried out during the decision-making procedure; it is done in order to easily understand which are the steps taken along the work. Right after the Figure 9, the explanation of each one of the stages involved in the process is done.

![Figure 9. Decision Making Process (Kiker, et al., 2005, p.105)](image)

A description, based on Triantaphyllou, et al. (1998, pp. 1-2), of the mentioned concepts in the Figure 9, is done below:

1. **Definition of the Problem & Solutions**: The different possibilities defined in the section 2 of the report.

2. **Identification of Criteria**: The range of characteristics that have to be accomplished by the solutions. Based in the research sub-questions and set up as milestones to achieve in order to be as successful as possible in reaching an answer for the main research question.

   There are 8 different criteria and all are related to the research sub-questions. The objective of them is describe an specific characteristic for, afterwards, assess how successfully achieve the solutions the criterion.

   - **Economical Cost**: The economical issues included in this part are the ones
regarding the cost of the system. Initial investment and maintenance are the main expenses. The quantities are given in US dollars.

- **Return on investment for Pamoja Cleantech AB:** The assessment of the potential revenues that the company could have out of the application of the various studied systems.

- **Development Empowerment:** This criterion tries to evaluate how the proposed solution can promote the local business, and give an extra-value to the activity that is currently going on in the area. For example, the service of cheap energy, for the processing of coffee husk, could mean an important advantage as the manufactured coffee increases three times its price compared to the current non-treated product.

- **New Business Opportunity:** The potential that the application has to create new job opportunities within a currently on going activity or, what is more interesting, the capacity that the system has to generate new business activities, thus economical growing.

- **Population Coverage:** The different activities on going in the region occupy different sectors and number of people. This criterion is measured as the percentage of people affected by the solution over the total population of the community.

- **Electricity Use:** The criterion measures the quantity of energy used. The energy consumption, given in kWh/year, needed to run the proposed solution.

- **Environmental Care:** Each solution will be assessed by how it is adapted to the GP location and its environment. The key factors influencing upon this criterion are the estimated contamination (manufacture and use), the alteration on its surrounding (view, noise, etc.) and other eventual contamination the system could cause.

- **Life span:** The estimated life span given by the manufacturer. Is measured in years.

In the thesis work case, the level of performance of each solution per each criterion is graded following two options, as shown in Table 4, and depending on the solution to be assessed.
Table 4. Value/Measure of the Criteria

<table>
<thead>
<tr>
<th>Numerical Option</th>
<th>Evaluation/Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economical Cost</strong></td>
<td><strong>US Dollars</strong></td>
</tr>
<tr>
<td><strong>Population Coverage</strong></td>
<td><strong>%</strong></td>
</tr>
<tr>
<td><strong>Electricity Use</strong></td>
<td><strong>kWh/year</strong></td>
</tr>
<tr>
<td><strong>Life Span</strong></td>
<td><strong>years</strong></td>
</tr>
<tr>
<td><strong>No Numerical Option</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Return on investment for Pamoja Cleantech AB</strong></td>
<td>1 → Very Unfavourable</td>
</tr>
<tr>
<td><strong>Development Empowerment</strong></td>
<td>10 → Highly Recommendable</td>
</tr>
<tr>
<td><strong>New Business Opportunity</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Environmental Care</strong></td>
<td></td>
</tr>
</tbody>
</table>

As Table 4 shows, the numerical values are obtained directly after the data collected in the field trip or after the information from the suppliers of the solution, if it is a device or a system. In the case of the non-numerical values, the authors of this thesis work decide the performance grade. These grades are the ones that are going to be applied in the mathematical equation, which is going to rank the solutions from the best performance to the less promising. This is possible because the WPM is referred also as a dimensionless analysis. The WPM structure eliminates any units of measure so different units can be assessed in the same analysis (Triantaphyllou, 2000, p. 8).

3. **Weight the different criteria**: It defines the value of each of the different criteria. Not all them have the same relevance from the DMs point of view, and the way to set the priority of the DMs is to grade the criteria according to the level of relevance for the study. In order to do that, in this case the result of adding up the weight of the entire criterion is 1.

4. **Eliminate the Inapplicable Solutions**: During the development of the analysis it is possible to see and understand that a considered solution can be discarded if its performance for the most relevant criteria, the ones with higher weight, is way worse than the rest of the possibilities.

5. **Determinate the Performance of the Solutions**: In this stage the different solutions have to be evaluated per each of the established criteria, this is done according to what has been explained in the Table 4.

6. **Final Ranking of Solutions**: Final result of the mathematical operation, which results in a ranking of the possible solutions assessed regarding to the criteria applied and its weight.

In order to have an approximate but coherent idea of the evaluation of each of the criteria; catalogues, papers, brochures of companies and other relevant information have been taken in account for each of the different possibilities. Thus, having an actual
reference in the study adds value and credibility to work for the statement of the figures and its comparison. The aforementioned data will be included in the Appendix V.

Finally, expose that the WPM has been selected because of its simplicity, the possibility of working with different units, the versatility in terms of adding and subtracting items from it, and essentially because it is the MCDA method that better adjusts the specific characteristics of the goals and objectives for the purpose of the project, the constraints and the multiple possibilities that a starting project has to offer.

The last step of this stage is to define which are the selected solutions included for the development of the project. Defining them and its parts is crucial for the following stages of the thesis work. And it links this part with the first step of the next stage, the overview of the design.

3.2 Potential Impact Identification of the Selected Solutions

The evaluation includes the following segments under each product sub-title:

- The overall benefits of the application in terms of community, household and industrial development levels. A design overview of the application that explains how the system looks and works and what the components are used.

- After all, the potential impact assessment has been carried out for each application. The assessments include “Potential Social Impact Assessment”, “Potential Environmental Impact Assessment”, and “Potential Economical Impact Assessment”. Again the detailed methodology about the potential impact assessment is given below.

The schema below represents the mentioned different sub-titles and the processes that are explained above; see Figure 10.
3.3 Final View of the System

The final view of the system is a design based on the previous overview created at the beginning of the results section (5.2.1 General Overview of the system), and improved when possible based on the assessments done during the research. The objective of this section is to try to merge all the applications in one in order to give more realistic figures and data. The final view of the system consists of two parts, the design of the system as a layout located on the selected village, and a brief budget containing the more relevant data, which can give an approximated idea of the assumed costs of the implementation of the system.

3.3.1 Budget

The budget will be spreadsheet based. In order to obtain a correct and successful budget, the following steps should be studied; paying special attention to the inclusion of all the parts involved in the product, regarding technical parts, all the devices belonging to the system. Once the spreadsheet is finished, the budget is completed. The list of the devices included in the spreadsheet can be as detailed as wanted, from general devices to small parts, depending on the technical list used and the supplier’s capacity.

3.3.2 Final Layout of the System

In this section, an overview of the final product will be given. The model will explain both the physical parts of the product and the relationships between different elements and stakeholders. By looking at this model, the reader should be able to observe how the product works and to examine the performance of the product. This understanding is done by the presentation of a hypothetical scenario based on the data collected during the field trip, and analyzed throughout the results part.
4. Field Trip

The field Trip section is, as explained in the methodology, divided in four sub-sections, the first two related to the data collection, and the two that are explained last in the chapter are regarding the interpretation of data. The results are ought to merge the different parts of the project in order to answer the research question. This section is principally trying to answer the sub-questions: “How to adapt the business approach to the community’s life-style in order to be well accepted”, “How to foster the development of the area by having a positive socio-economic impact on society” and “How to achieve the maximum efficiency in terms of reusing waste, cradle-to-cradle approach”

4.1 Site Visit Preparation

The preparation of the site visits starts before the trip itself. During the previous month, the background research helps to set up the data boundaries, to constraint the search of information and the surveys to what is completely relevant; focusing in the scopes of high interest as energy consumption and life-solutions. During this time, the survey that can be found in the Appendix III is developed and thus having a guideline for the data to be sought; as it is stated in the methodology section 3 Methodology, the survey is used for the identification of the potential site as well.

Once this background work is done, the next step is to perform the trip to the locations. To do so, the researchers take advantage of the NGO Vi-Skogen. The collaboration aim is to identify the conditions and community needs. The work of the NGO, which is useful for this research, is the transformation of agricultural communities into cooperatives, fostering their development and increasing the yield ratio. Therefore, it is easy for them to highlight areas where the agricultural cooperative could be a good spot for the GP pilot plant, knowing beforehand what the needs of Pamoja Cleantech AB are.

In this direction, the sites recommended by Vi-Skogen are: Magala Growers Cooperative and Nabumbugu Coffee Farmers. Then, to start the research, the main points of observation are made in connection to “i) the locality and demographics”, “ii) energy supply assessment, considering the production rate of the village, the main crops, the agricultural residue rate” and “iii) energy demand assessment, considering uses and costs of energy, energy sources, difficulties in energy supply and social needs. In order to collect this information a questionnaire is used”, see Appendix VI. Another collaboration with a different stakeholder in Uganda, CREEC, has been performed at the same time. This organization provides advising and the experience of having been working in the field for many years.

Throughout the field trip, a number of surveys were also conducted. The local inhabitants have participated in the surveys. Mainly, the surveys are done with the farmer families. The details and result about the surveys are given in the result section (4.2 Surveys of Visited Sites). Once this information being arranged and analyzed, it will be used to select the most promising site for the pilot plant. Then, the specific data of
this particular place (life-solutions, consumption, and willingness of pay) will serve for the MCDA process, and further on for the potential impact illumination.

A conceptual map is shown in order to clarify this explanation, see Figure 11.

![Conceptual Flow and Use of Data](image)

4.2 Survey of Visited Sites

In this part of the chapter, it is given the result of the surveys, which are performed in the three sites visited. The data gathered during the field trips is exposed following the surveys in Appendix III, this data is used to select the potential site location of the GP.

1. Visit to: Esukanesi Memorial Primary School

This visit is a particular initiative of the two authors of this thesis paper. During the visit, the data is gathered in order to include this visit into the potential pilot villages. Even though this site is not considered for the installation of the pilot plant, the information, the comments and the experience achieved during this trip is seriously taken in account,
not for its direct repercussion on the project but for the vision of the local people which not differ much between the different areas in the country.

1. **Area**
   
   1.1. **Geographical placement**
   The school is placed in Kisiita – Kawoko, Butenga Sub-County, Bukomansimbi County, Masaka District on Sembabule Road. It is a pretty isolated place, there is one road passing throughout the village but there is not pavement.

   1.2. **Extension of the village, community, town. (Approximate distances)**

   1.3. **National grid expansion possibilities**
   There is a grid existent all along the road that connects the different houses and the village, which is really extended. The village is divided in two different councils, due to its large extension.

2. **Population**
   
   2.1. **Households**
   The population of the area is around 800 people.

   2.2. **School covering**
   The local school has 300 students, which means almost all the kids go to the school in the area. There is a high motivation of education, in terms of increasing their chance of success in the active labor life and their socio-economical conditions.

   2.3. **Economical level (possibilities of consumption, will of payment, capacity of acquiring devices which need of energy, etc.)**
   The population of the area does not dispose of a high amount of money per family.

3. **Industrial/Commercial/Social activities**
   
   3.1. **Main activity**

   3.1.1. **Industrial (Cooperatives, farms, mills, etc.)**
   The zone does not dispose a well-structured industrial area. There is only one mill, which is situated far away from a big part of the village (due to the extension of the town itself). The main activity of the area is the agriculture; principal crops are coffee, banana and maize. Some people are dedicated to the production of mood bricks for construction. All labor is done by hand; there are no tractors or mechanical equipment involved. The whole village just disposes of one small truck, which is from private property.

   3.1.2. **Commercial (Markets, stores)**
   There are three main grocery stores in the village; just one of them has access to electricity by a diesel generator.
   Water pumping and cleaning could be an option; there is no communal water net.

   3.1.3. **Social (Schools, cultural houses)**
   There is one primary school in the area. The school is more than an educational centre, it is a point of meeting between people and represents an element that all are proud of. The school was formed by the initiative of one particular person, but after that all community has pushed in order to make it grow and develop. It is a symbol of community spirit and social collaboration. In the school the kids learn as well how to crop and how to work the land, in doing so the children learn to be self-sufficient in life.

   3.2. **Energy consumption per sector (estimated)**

   3.2.1. **Industrial**
In agriculture and the other industrial activities the consumption of energy is really low. Most of the works are done manually, without involving any mechanical machine or electrical device.

3.2.2. Commercial
The only store that has electrical power gets it from a diesel generator.

3.2.3. Social
The school has a diesel generator at its dispose but the price of the fuel makes it hard to use it. There are few small solar cells that provide a small amount of electrical energy that is used to light just one room of the school during a short period of time, it is a really low amount of energy.

3.3. Population involved in these activities
Almost all the community is dedicated to the two main economical activities, agriculture and brick production.

3.4. Further possibilities (cooperative creation, implementation of other activities, such milling if there is not currently existing)
There is a strong community feeling and, with the school as an example, it could be possible to engage people to create a cooperative where they could mill the maize and corn (which means one of the principal elements in their diet).

4. Current energy resource(s)
The main energy resources are the diesel, charcoal and firewood.

5. Biomass supply possibilities (agricultural activity)
5.1. Amount of activity (possible cover plant needs)
High agricultural activity exists in the region. Nevermore, there are not a specific number of tons per year of agricultural waste.

5.2. Type of crop
The main crops are banana, maize and coffee.

6. Social energy requirements
6.1. Households (cooking, light, etc.)
The possibilities of consumption in the households are not very high, mainly due to:
- There is already a way of life based on a non-electrical dependence,
- The revenues per family are really low and there is not a real need of having electricity in the houses,
- The main customer for the electrical consumption would be the community as one unit.

6.2. Community needs (milling, water pumping, food stocks conservation, medicine, etc.)
Water pumping service to the school or to a specific point of the town would be a strong need, as well as the disposition of a mill which all the farmers could use. The fact that the village is so extended is a problem. There is going to be always a part of the community far from the energy providing point.

6.3. Other needs.

7. Conclusion
The main necessities detected after the visit are:
- Water services. The community use rainwater for all dairy activities: washing,
cleaning, drinking, cooking, etc. The school has a deposit, which collects all the rainwater from the rooftops of the buildings that shape the school. The rest of the community collects water from a manual pump, which is far away from most of the households that form the community.

- Milling. All the members of the community have to cover a long distance in order to access the grinding facilities. As milled maize is an important part of their diet, it results in a big need. It could improve their economical status and they could ensure a source of food, due to the use that they do out of maize flour.

- Electricity. There is a grid passing through the village but because problems with the transformer there is no electricity at community disposal. Despite of it, most of the members of the community wouldn't use the national grid electricity because their economical conditions; electricity prices are really high considering to the electricity demand. Regarding to light use, nowadays they just have light in one of the rooms of the school, it runs by a diesel generator which is really expensive, the lighted place is used for cooking and eating, just to light the room where most of the people living close to the school cook, it is also a social meeting point because there is no other place with this service around the school.

- Cooling System. There is no cooling service for the community, the storage of products is a problem, milk, meat, and etc. cannot be stocked.

- Cooking. They cook with charcoal stoves, this is not a big problem but the inhalation of the charcoal smoke can produce a number of dangerous diseases.
2. **Visit to: Magala Growers Cooperative. Sekanyonyi, Busunju Area.**
After meeting with Vi-Skogen the research group arranged a meeting with the head of the Busunju District branch.

1. **Area**
   1.1. **Geographical placement**
   Time gap, 15-20 minutes by car from Busunju. 1 hour 45 minutes by car from Kampala.

1.2. **Extension of the village, community, town. (Approximate distances)**
The village is quite extended in the region; there are big distances between households; around 6 km².

1.3. **National grid expansion possibilities**
Currently the national grid is not reached to the region, and as it is a relatively isolated area the national grid extension plan does not cover the site.

2. **Population**
   2.1. **Households**
   There are 110 households members in the cooperative, accounting 8 members per household.

   2.2. **School covering**
The village has two schools and there are another 8 schools in the area.

   2.3. **Economical level (possibilities of consumption, will of payment, capacity of acquiring devices which need of energy, etc.)**
The business is highly depended on the agricultural activities. The economical conditions are relatively higher compared to the other villages. The need of electricity is high and the pilot project promises a potential economical development.

3. **Industrial/Commercial/Social activities**
   3.1. **Main activity**

   3.1.1. **Industrial (Cooperatives, farms, mills, etc.)**
   There is just one maize mill currently at the cooperative disposition. Regarding groundnuts there is one small portable machine that separates the husk from the seed. Both of the machines they work with a diesel generator. For the coffee treatment they have to move to another village where they can use a machine.

   3.1.2. **Commercial (Markets, stores)**
   There are 2 grocery stores in the villages. The main goods are basic food stocks (rise, eggs, vegetables etc.) and some fast moving consumer goods (FMCG).

   3.1.3. **Social (Schools, cultural houses)**
The main social meeting point of the village is the center of the village where the research team has been doing the surveys. The villagers are given some solar lamps by the Vi-Skogen and the main charging point is that center.

   3.2. **Energy consumption per sector (estimated)**

   3.2.1. **Industrial**
   For the treatment of the agricultural production the energy consumed by the cooperative is mainly the diesel. In addition the national grid electricity is the part of their industrial activities. Nevertheless this electrical consumption is taking part in another village.

   The estimated consumption per crop is:
Maize → 10 litres of diesel/day; the machine is working everyday during 2 peak months per season. 4 months/year full capacity.

3.2.2. Commercial
The commercial markets have no electricity. But in the center they use the small solar charging lamps and the kerosene lamps.

3.2.3. Social
The solar charging lamps and the kerosene lamps are the only accounted. The consumption of kerosene in the village due to lighting needs:

Kerosene → 2.5 litre/household and week.
Kerosene price → 3.000 UGX/litre. 1.06 USD/litre.

3.3. Population involved in these activities
3.4. Further possibilities (cooperative creation, implementation of other activities, such milling if there is not currently existing)

4. Current energy resource(s)
The available energy in the village is based on oil, firewood and charcoal, all these energy sources have to be transported to the village.

In comparison, the price of electricity is:
Electricity → 450 UGX/kW + VAT (tax on electricity = 100 UGX/kW)

5. Biomass supply possibilities (agricultural activity)

5.1. Amount of activity (possible cover plant needs)
Regarding to the households (members) of the cooperative that are producing each of the crops:

- Maize, large-scale → 70 members – 3 acres/member
- Coffee, large-scale → 73 members – from 1 to 4 acres/member
- Beans, large-scale → 68 members – 1.5 acres/member
- Groundnuts, small-scale → 20 members – 0.5 acres/member

These figures are the ones that account the harvest of the whole cooperative:

- Maize → 70.000 kg/season (2 seasons) – 140 tonnes/year
- Coffee → 20 bags/season (2 seasons) – 70 kg/bag – 2.800 kg of coffee/year
- Beans → 700 kg/member and season

As lately the price of groundnuts in the market is increasing, the organization is seriously thinking on expanding the production to that product as well.

5.2. Type of crop
Market production

- Maize
- Coffee
- Beans
- Groundnuts (self-consumption yet)

6. Social energy requirements

6.1. Households (cooking, light, etc.)
6.2. Community needs (milling, water pumping, feedstock conservation, etc.)
6.3. Other needs.

7. Conclusion
This village is the most promising one in terms on existing industrial activities and the
potential development opportunities. The main needs of the community could be listed as following:

- Electricity for agricultural activities: machinery, water pumping and milk storage.
- Electricity to create new business: the trade center where the small shops are or hair-dresser (which was the one of the first demands of the community)
- Electricity for domestic uses: lightning, cooking
- High production rate
- Telecom base station near the village working under a diesel generator.
- Efficient cooperative organization
- Micro-financing possibilities, expanding machinery.

Figure 12. Community of Sekanyonyi During the Development of the Survey
3. **Visit to: Nabumbugu Coffee farmers CO, Busunju Area.**
This trip was part of the visits performed with Vi-Skogen in the Busunju Area. The ongoing Vi-Skogen project in the site is the training and the leading implementing methods for water management and efficient plantation. They have improved significantly their potential and production rate of coffee. Vi-Skogen helped and assisted the farmers in order to increase their productivity by different methods based on plantation management. There is currently ongoing a micro-finance system within the members of the organization. There is a governmental micro-finance program but it is not working as good as their own, as they say. As a cooperative they work together in the sales-agricultural market. They say that working as a group has increased their business capacity on 600 UGX/kg of coffee, which means that, per each kilogram they sell as cooperative they earn 600 UGX more than selling the same as individual farmers. There is one member of the cooperative that owns agricultural machinery; this facility is used of the whole cooperative.

1. **Area**
   1.1. **Geographical placement**
   Approximately 45 minutes away by car from Busunju village.
   1.2. **Extension of the village, community, town. (Approximate distances)**
   The village is a bit more compact than the villages visited previously, although as most of the villages visited it covers a large territory.
   1.3. **National grid expansion possibilities**
   There is access to the national grid; the main issue against it, is that the electricity price is very high compared to the demand.

2. **Population**
   2.1. **Households**
   There are 15 groups within the cooperative organization. The groups are formed by 15 members and so there are approximately 225 households dependent on the organization.
   2.2. **School covering**
   2.3. **Economical level (possibilities of consumption, will of payment, capacity of acquiring devices which need of energy, etc.)**

3. **Industrial/Commercial/Social activities**
   3.1. **Main activity**
      3.1.1. **Industrial (Cooperatives, farms, mills, etc.)**
      There are some machines available for all the farmers, the whole facility for coffee treatment and for maize milling.
      3.1.2. **Commercial (Markets, stores)**
      3.1.3. **Social (Schools, cultural houses)**
   3.2. **Energy consumption per sector (estimated)**
      3.2.1. **Industrial**
      The energy consumption of the community is mainly based on the amount of harvest, due to the dependence on electrical supply, and the diesel prices, the consumption is tightly related to their economical capacity.
      The estimation of the need of energy can be calculated out of the machinery they use.
For coffee treatment:
- Husk treatment → 18 kW
- Filter, separation of the husk and the seed → 2 kW < X < 4 kW (approx.)
- Packaging (bags) → 3 kW

The system is used 8 months/year, 4 months each harvest. And the running of the machines during this period depends on the coffee availability.

Involved in the coffee treatment there is the previous drying. It is dried by sun-heat, and so it is difficult to estimate how long is the process going to take, giving them the chance to dry it with some source of heat would improve their process, thus reducing cost and speeding up the whole production.

Maize milling, 2 machines, but it is out of our range:
- Maize milling engine → 3 kW
- Bagging → no data.

Despite of the machinery the milling of maize is just directed to household-use level, there is no business out of maize flour in that cooperative.

3.2.2. Commercial
3.2.3. Social

3.3. Population involved in these activities
3.4. Further possibilities (cooperative creation, implementation of other activities, such milling if there is not currently existing)

4. Current energy resource(s)
The main energy resources are the diesel, charcoal and firewood.

5. Biomass supply possibilities (agricultural activity)
5.1. Amount of activity (possible cover plant needs)
There are two agricultural activities that are relevant, but just one of them is dedicated to business making, which is coffee; maize is just for domestic consumption.
- Coffee: 50.000 kg/season → 100 tones of coffee produced per year, this figure is for dried coffee.

Regarding to the sale market, there is an important figure which should be remarked, the difference between selling the coffee treated or not. The gain for the organization is more than twice the price.
- Not treated coffee → 2.200 UGX/kg
- Treated coffee → 4.500 UGX/kg

The farmers say that they are able to sell high-priced coffee due to the quality of the product.

5.2. Type of crop
- Coffee (Market production)
- Maize (Household consumption)

6. Social energy requirements
6.1. Households (cooking, light, etc.)
6.2. Community needs (milling, water pumping, feedstock conservation, etc.)
6.3. Other needs.

7. Conclusion
The potential of the village, regarding the amount of production and the machinery
available is very high; the main problem is the proximity and the current use of the national grid. The requirements of the project constrain this place where the grid is established. The farmers claim that they are ready and in good disposition of making an economical effort to improve their facilities if the plant is finally placed there. In the Figure 13 is possible to see the headquarters of the Nabumbugu cooperative.

![Nabumbugu Coffee Growers Cooperative, Headquarters](image)

There are sections of the surveys that are not filled; is due to the lack of information given by the farmers and the local people.

Once the surveys are complete, the selection of the potential site takes place. This is done by the analysis of the collected data and the agreement amongst all the team involved in the GP project, which is Pamoja Cleantech AB group. In the next section, the Pilot Site selected is described.
4.3 Pilot Area

This chapter includes: grouping the data, detailing the analysis, arguing on the potential options, and the discussion amongst the researchers and the Pamoja Cleantech AB members who help to qualify the location for the pilot plant. The final decision is to place the pilot plant in Sekanyonyi, that means selecting the **Magala Growers Cooperative**. This decision has been made by the requirements of the stakeholders and Pamoja AB. One of the main conditions which have been looking for is to have the potential of creating new business opportunities in the village and also to foster the agricultural activities. Magala Growers Cooperative was the most organized community among the others and had a promising social background. The relevant data for the selection of the pilot plant is given below, see Table 5, Table 6, Table 7, Table 8 and Table 9.

Table 5. General Information of the Pilot Area

<table>
<thead>
<tr>
<th>Community Current Situation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>110 households</td>
<td>880 people (approx.)</td>
</tr>
<tr>
<td>Area of the Village</td>
<td>The village is spread along 6 km²</td>
<td></td>
</tr>
<tr>
<td>Schooling Rate</td>
<td>8 schools in the area (2 reachable for mini-grid)</td>
<td>High schooling among kids</td>
</tr>
<tr>
<td>Active Local Organization</td>
<td>Magala Cooperative</td>
<td>3 years of work experience</td>
</tr>
<tr>
<td>National Grid</td>
<td>Not connected and not planned in long time period</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Agricultural Production in the Pilot Area

<table>
<thead>
<tr>
<th>Current Agricultural Production</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>Coop. members</td>
<td>Production</td>
</tr>
<tr>
<td>Maize</td>
<td>70</td>
<td>3 acres/member</td>
</tr>
<tr>
<td>Coffee</td>
<td>73</td>
<td>1 to 4 acres/member</td>
</tr>
<tr>
<td>Beans</td>
<td>68</td>
<td>1.5 acres/member</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>20</td>
<td>0.5 acres/member</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Household Energy Use

<table>
<thead>
<tr>
<th>Household Energy Use</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking Use</td>
<td>Meals per day</td>
<td>3 meals total</td>
</tr>
<tr>
<td>Time per meal</td>
<td>4.5 hours total</td>
<td>0.5 hours</td>
</tr>
</tbody>
</table>

---

² So far is just produced for self-consumption. Although, lately the prices in the market started rising and the cooperative is open for business considerations.
### Energy Need

<table>
<thead>
<tr>
<th>Energy need</th>
<th>3 firewood pack per day for cooking the meals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Boiling</td>
<td>10 litres per household per day</td>
</tr>
</tbody>
</table>

#### Lighting

<table>
<thead>
<tr>
<th>Lighting</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooms lighted</td>
<td>5 rooms</td>
</tr>
<tr>
<td>Time lighted</td>
<td>5 hours average</td>
</tr>
</tbody>
</table>

#### Others

<table>
<thead>
<tr>
<th>Others</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-solar cell</td>
<td>Phone charging</td>
</tr>
</tbody>
</table>

Table 8. Current Energy Consumption

<table>
<thead>
<tr>
<th>Total Energy Consumption</th>
<th>(Uganda GDP per capita = $500, UNData, 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Current Consumption</td>
</tr>
<tr>
<td>Kerosene</td>
<td>2.5 litre/household*week</td>
</tr>
<tr>
<td>Diesel</td>
<td>70 litres/week</td>
</tr>
<tr>
<td>Charcoal</td>
<td>260 kg/month (4 bag/month)</td>
</tr>
<tr>
<td>Firewood</td>
<td>3 bundles/day</td>
</tr>
</tbody>
</table>

Table 9. Machinery Power and Energy Consumption

<table>
<thead>
<tr>
<th>Current Machinery</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
<td>Power</td>
</tr>
<tr>
<td>Diesel generator</td>
<td>9.7 kW</td>
</tr>
<tr>
<td>Maize mill</td>
<td>7.5 kW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Consumption for the Machinery</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Fuel</td>
</tr>
<tr>
<td>Diesel Generator</td>
<td>Diesel</td>
</tr>
</tbody>
</table>

The area covers much of the requirements for the implementation of the pilot-plant. The fact is that the production rate is really high, compared to the other options. Thus, it makes this place the best of the possibilities in terms of feedstock supply and potential of creating new productive activities; see Table 6. The capacity of the agriculture cooperative regarding to the economical potential is promising as well, since they have the possibility of enhancing the farmers by micro-financing. The only weakness is the current disposition of machinery, even though this becomes less problematic because of the micro-finance possibilities; see Table 9.

The chance of allocating a mill, in the community, would be crucial. First of all, it is important to reduce the distances that the farmers have to cover in order to process their products, and secondly, all the farmers could get benefit out of it (even the ones that do not belong to the cooperative). Besides, the placement of the GP would not be a problem since all the facilities are already established in the same area or nearby the cooperative. They are close to each other in order to improve the efficiency of the production and reducing time and costs. Another positive key point of the location is the presence of a telecom tower in the region, which should be the main customer and the

<sup>3</sup> Working on 7 hour/day regime.
principal revenue stream for the Pamoja Cleantech AB business model.

Once the location is decided, the next step is to define the main life-solutions that can be provided to the community, both in the households and the cooperative.

4.4 Applications and Life-Solutions

Throughout the site visits, surveys and analysis of the collected data, (see Tables 5 to Table 9), the main needs of the society have been identified. In order to convert this information into a useful source of knowledge about the life-solutions to be provided, the following tables link the potential applications studied (section 2.3 The Green Plant and the Potential Applications) to the life-solutions that those could cover; see Table 10 and Table 11.

The data exposed in the Table 10 and Table 11, is organized according to the level of impact that is communal or productive use. These terms are defined below for a better understanding:

- **Community** (see Table 10)
  It includes all solutions that are meant to attend social needs. Not implicating any direct economical gain for the stakeholders. There are two sub-levels:
  - Community as entire village or organizations within the village.
  - Household as individuals or family level.

- **Productive Use** (see Table 11)
  It regards mainly agricultural-related activities. The solutions aim to cover the drawbacks of the lack of electricity.

The benefits that are described on the following tables (Table 10 and Table 11) are the direct contribution of the life-solutions to the people, the positive impact intended to provide.
<table>
<thead>
<tr>
<th>Community Level</th>
<th>Potential Application</th>
<th>Life-Solution</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>Battery Charging</td>
<td>Lighting</td>
<td>Time efficiency, productivity increase, educational progress, improved security and a richer social life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery charging</td>
<td>Locals don’t have to go to another town to charge their cell-phones’ batteries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leisure time</td>
<td>Local people can listen the radio or do any other activity to spend their spare time</td>
</tr>
<tr>
<td></td>
<td>Mini-Grid</td>
<td>Lighting</td>
<td>Time efficiency, health improvement in the households, productivity increase, educational progress, improved security and a richer social life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrification of facilities</td>
<td>Community facilities, schools, cooking spots, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery charging</td>
<td>Locals don’t have to go to another town to charge their batteries. Time efficiency.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Health-care</td>
<td>Improvement in health-care facilities or possibility of establishing new ones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beauty Salon</td>
<td>Possible improvement in self-care and hygienic conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Refrigeration of food</td>
<td>Possibility of storing food products for a longer time and in better conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leisure time</td>
<td>Local people can listen the radio or do any other activity to spend their spare time</td>
</tr>
<tr>
<td>Household</td>
<td>Absorption Chiller</td>
<td>Refrigeration</td>
<td>Possibility of storing food products for a longer time and in better conditions</td>
</tr>
<tr>
<td></td>
<td>Battery Charging</td>
<td>Lighting</td>
<td>Time efficiency, health improvement, educational progress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phone charging</td>
<td>Possibility of charging devices at home</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leisure time</td>
<td>Members can use their increased leisure time listening radio, or doing other activities</td>
</tr>
<tr>
<td></td>
<td>Mini-Grid</td>
<td>Lighting</td>
<td>Time efficiency, health improvement, educational progress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery charging</td>
<td>Possibility of charging devices at home</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leisure time</td>
<td>Members can use their increased leisure time listening radio, or doing other activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Refrigeration of food</td>
<td>Possibility of storing food products for a longer time and in better conditions</td>
</tr>
</tbody>
</table>
### Table 11. Potential Applications, Life-Solutions and Benefits for the Productive Use Level

<table>
<thead>
<tr>
<th>Productive Use Level</th>
<th>Potential Application</th>
<th>Life-Solutions</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mini-Grid</strong></td>
<td>Lighting</td>
<td>Opening business longer hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity Power</td>
<td>Possibility of working with better and more equipment</td>
<td>Time-saving devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capacity for better and more equipment</td>
<td>Improvement in product processing</td>
</tr>
<tr>
<td><strong>Heat Pipe Exchanger</strong></td>
<td>Drier</td>
<td>Speed up drying process, capacity of previewing drying time and planning the rest of the processing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refrigeration</td>
<td>Refrigeration of spaces such as the container or the battery hub</td>
<td></td>
</tr>
<tr>
<td><strong>Recuperator</strong></td>
<td>Drier</td>
<td>Speed up drying process, capacity of previewing drying time and planning the rest of the processing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refrigeration</td>
<td>Refrigeration of spaces such as the container or the battery hub</td>
<td></td>
</tr>
<tr>
<td><strong>Absorption Chiller</strong></td>
<td>Milk Storage</td>
<td>Refrigeration of a closed thermally-isolated space where milk can be stored at an appropriate temperature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refrigeration</td>
<td>Refrigeration of spaces such as the container or the battery hub</td>
<td></td>
</tr>
<tr>
<td><strong>ORC Turbine</strong></td>
<td>Mechanical Shaft</td>
<td>Providing shaft for the functioning of the mills and other agricultural processing machinery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity Production</td>
<td>Capacity of producing a small amount of electricity for other purpose</td>
<td></td>
</tr>
</tbody>
</table>

As a brief and first conclusion of the applications’ overview, it can be seen following the Table 10 and Table 11, that the systems that can cover most of the needs are the ones related to rural electrification; battery charging system and mini-grid.

This analysis must be used as an overview of all the possible uses that can be given to the energy sources available. The definitive applications, the study of how each of them could be commercialized and served to the community or the agricultural processes will be explained in the section 5 Results.

Previous to the further analysis of the selected applications, there is a mandatory first step; the introduction and assessment of the system design, has to be done in order to have a good understanding of the processes on going, and so help to identify the related opportunities and impacts. This part builds what is fundamentally a starting point to base the further analysis and to identify the potential impacts. The design given in this
part is the base for the final system, and only the small modifications that could improve it significantly are the ones that would be performed.

The development of this part starts with the design of the mini-grid (A), then the BCS (B) and finally the heat pipe exchanger (C).

**General View of the Applications**

**A. Mini-Grid**

To start understanding what the mini-grid could mean for the local people is important to see the direct benefits of the life-solutions that each application can provide. In order to do that the table below shows the relation between those elements for the mini-grid, see Table 12 and Table 13. The data collected throughout the field trip and previously assessed in the project is used to achieve these conclusions (Table 6 to Table 11). Although, it is not the only used source of information; other papers and official reports, such as the report of the World Bank Independent Evaluation Group, (2008), have been taken into account as an example of already assessed impacts.

**Table 12. Potential Life-Solutions and Benefits Provided by the Mini-Grid for the Community & Household Level**

<table>
<thead>
<tr>
<th>Life-Solution</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lighting</strong></td>
<td><strong>Time efficiency:</strong> Providing lighting could save time of gathering other possible light sources as firewood or kerosene. Another time-saver comes after the chance of working or doing home-tasks after the natural light is gone</td>
</tr>
<tr>
<td></td>
<td><strong>Productivity increase:</strong> The possibility of working longer hours and more easily. Clear and instant lighting could improve community conditions allowing the implementation of communal productive activities</td>
</tr>
<tr>
<td></td>
<td><strong>Educational progress:</strong> Kids and adults can read and improve their educational level in community areas provided with lighting. They could have after school lessons in a shared house with lighting</td>
</tr>
<tr>
<td></td>
<td><strong>Improved security:</strong> Street or communal lighting could provide security during night-time due to the increase on illumination; robberies or burglaries could be reduced or more likely spotted</td>
</tr>
<tr>
<td></td>
<td><strong>Richer social life:</strong> The lighting of commune areas would activate social activities and the likelihood of sharing the free time, strengthening the relationship between community members</td>
</tr>
<tr>
<td></td>
<td><strong>Health-care:</strong> The possibility of reducing the kerosene lamps, or other lighting devices that mean combustion of any fuel, would directly affect the quality of indoor air, reducing the percentage of harmful particles breathed by the people inside any commune shelter</td>
</tr>
<tr>
<td><strong>Battery Charging</strong></td>
<td>The local people would not have to go to other villages to charge the batteries of the different devices like phones, radios or any other. It would imply timesaving as well.</td>
</tr>
<tr>
<td><strong>Health Care</strong></td>
<td>The opportunity of starting a health-care service that could provide the community</td>
</tr>
</tbody>
</table>
with first-aid kits or other public health items.

| Beauty Salon | The chance of having a beauty salon service in the area would directly imply a timesaving for those services, avoiding the trips to other places to have access to the service. |
| Refrigeration of food | The possibility of storing food products, for a longer time and in better conditions for community consumption, would mean a better feeding and increased capacity to avoid digestion diseases. |
| Leisure time | The capacity of spending the leisure time in better conditions, increasing comfort and giving the chance of using electronic devices as radios or televisions, which at the same time can help to be aware of political, social or any other kind of events. |

Table 13. Potential Life-Solutions and Benefits provided by the Mini-Grid for the Productive Use Level

<table>
<thead>
<tr>
<th>Life-Solution</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>The opportunity of longer business time; opening after sunset could increase revenues of shops and home small-scale businesses. It would also allow the agricultural processing activities, such the husk processing of coffee, to be carried out during more hours a day, reducing the amount of days used to do this activity, and so, getting a more efficient use of time.</td>
</tr>
<tr>
<td>Electricity Power</td>
<td>Increase on revenues and give the possibility of expand the business capacity. Timesaving and more efficient devices. Improvement in product processing methods</td>
</tr>
</tbody>
</table>

After describing which are the potential contributions of the mini-grid to the community and the cooperative it is time to describe in detail what is the mini-grid, which are its parts, and how would it look like according to the data collected in the surveys. The design of the mini-grid has been mainly based in the methodology described in the Mini-grid Design Manual (Inversin, 2000). Although, this design work has been done with the best intentions, the theoretical approach has multiple drawbacks, and the major of those is the lack of specific data and real figures. The estimations that have been made during the development of this work have been based in the knowledge gathered all along the report and the thesis surveys and field trips.

The aim of this design is to illustrate how the mini-grid would look like, instead of reproducing an actual situation in Sekanyonyi. The design has not been done until the last steps due to the reasons mentioned before. Following the design guide defined by Inversin (2000), just the 3 first steps have been included in this report. Although another 3 steps can be found in the Appendix VIII, these are related to a more technical approach to the line and its characteristics, which can give an idea of the cost of the line conductor, and thus, a more accurate budget preview.

The parts defined below are the mini-grid demand assessment (I); the area mapping (II); and the system layout (III).
I. Demand Assessment. Mini-Grid Loads
The evaluation of possible demand is the first step to start the design of the mini-grid delivery system. The demand assessment has been based on the previously collected data and in the ideas and concepts developed all along the work and research. The telecom tower supply, as it has been mentioned in the previous parts of this work (Section 2.2 The Green Plant Concept, System Boundaries and Stakeholders) is taken in account in order not to consume its part of the supply, but is not included in the design performed due to lack of information about its exact placement and functioning.

The demand of the mini-grid is based on the 3 big groups of consumption that can be found in the pilot area, the Households (a), the Community Services (b) and the Productive Use (c). The differentiation of these 3 big units can be seen since the section 4.3 Pilot Area (from Table 5 to Table 9).

a) Household
The supply to the households, according to the research done, will be pointing mainly low-power demanding items like lighting, radios or phone chargers. Therefore, the simultaneous supply will not be high compared to the other uses. The estimation of coincident load per household can be seen in Table 14.

<table>
<thead>
<tr>
<th>Item</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulb</td>
<td>60 W</td>
</tr>
<tr>
<td>Radio</td>
<td>5 W</td>
</tr>
<tr>
<td>Phone charger</td>
<td>5 W</td>
</tr>
<tr>
<td>Others</td>
<td>10 W</td>
</tr>
<tr>
<td>Total coincident load/household</td>
<td>80 W</td>
</tr>
<tr>
<td>Total coincident load (110 household)</td>
<td>8.8 kW</td>
</tr>
</tbody>
</table>

In that way, it is possible to see, Table 14, that the maximum coincident load demanded by all households will be less than 9 kW, and so it is possible to supply the telecom tower (1 kW), which is meant to be the main GP customer and the peak household load at the same time.

b) Community Level
The delivering of energy to the community amenities is, at that point, still uncertain because there is no exact data about the demand that these activities will hold. To set a starting minimum load of demand for community services, the facilities that are placed in the village, the 2 schools and the 2 grocery stores, are accounted. So, the maximum load per facility is expected can be seen in Table 15.
Table 15. Estimated Electricity Consumption at Community Service Level

<table>
<thead>
<tr>
<th>Activity</th>
<th>Amount</th>
<th>Load</th>
<th>Total load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schools (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting (bulbs)</td>
<td>15</td>
<td>60 W</td>
<td>900 W</td>
</tr>
<tr>
<td>Leisure</td>
<td>5</td>
<td>100 W</td>
<td>500 W</td>
</tr>
<tr>
<td><strong>Total load per one school</strong></td>
<td><strong>700 W</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grocery Stores (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting (bulbs)</td>
<td>6</td>
<td>60 W</td>
<td>360 W</td>
</tr>
<tr>
<td>Small battery charging</td>
<td>6</td>
<td>100 W</td>
<td>600 W</td>
</tr>
<tr>
<td>Others</td>
<td>6</td>
<td>100 W</td>
<td>600 W</td>
</tr>
<tr>
<td><strong>Total load per one grocery store</strong></td>
<td><strong>780 W</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total load</strong></td>
<td></td>
<td></td>
<td><strong>2.96 kW</strong></td>
</tr>
</tbody>
</table>

The assessed demand is accounting the possible applications mentioned in the previous stages of this research (Section 4.4 Applications and Life-Solutions). As a conclusion and after analyzing the Table 15, two basic ideas can be identified:

- The assessed consumption per facility is the maximum that each facility can have, and so, the lining design will be based on this maximum energy demand per customer.
- The total load calculated is the minimum load that must be foreseen in the designing of line for the global community service supply. It must be the starting point and a likely reference for future grid extensions.

c) Productive Use

The demand of electricity for productive uses is reduced to the electrical motors, the electric devices and the lighting of the facilities, where the agricultural procedures are carried out. These activities are:

- Agricultural Activities. Seed drying (Heat Pipe Exchanger, see Appendix VI); Milling; and Lighting
- Battery System

- Agricultural Activities: In order to obtain the maximum efficiency in energy management, accounting the seasons and knowing about the agricultural processes is very important, especially because drying is previous to milling, and it is likely that all the harvest cannot be dried at the same time, so the first milling activity can be done during the last seeds are being dried. In the next table the demand for these agricultural activities is assessed, see Table 16.

Table 16. Estimated Electricity Consumption at Agricultural Level

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration⁴</th>
<th>Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed dryer</td>
<td>3 weeks per season</td>
<td>2.2 kW</td>
</tr>
<tr>
<td>Mill</td>
<td>2 months per season</td>
<td>9.54 kW⁵</td>
</tr>
<tr>
<td>Mill lighting (2 bulbs)</td>
<td>During milling</td>
<td>120 W</td>
</tr>
</tbody>
</table>

⁴ The farmers gave the data regarding the duration of the agricultural activities.
⁵ The conditions of peak demand change for the start-up period, see Appendix VIII.
Together with the Table 16, the Figure 14 show that the peak supply capacity of 12.2 kW it is almost reached one week per season; so, there is the harm of not being able to perform normally the daily productive tasks if the system capacity is exceeded. In order to prevent this to happen, the farmers will have to be aware and manage the productivity times to avoid possible problems in the energy supply, the coincidence of the two main agricultural activities (milling and seed drying) will be not possible, thus the selection of which activity is held will have to be done by the farmers.

Figure 14. Agricultural Peak Load Coincidence in Harvesting Season

- **Battery Charging System:** A battery back-up system is integrated into the mini-grid. It is not an application but part of the mini-grid system itself. It should not be considered as a separated service. The battery charging system can be connected to the grid during the low demand hours (night time), thus it is used as back-up resource during extreme demand-peak hours; this is the reason why there are no calculations about its demand. There is another benefit related to the implementation of this solution; the use of this energy storage during the night would increase the load factor of the system making it more efficient. The battery storage power is of 6.72 kW, and the inverter power has a maximum of 2.2 kWh. Thus, the batteries could be charged in less than 4 hours and be used during daytime if there is the need.

Looking to the diagram, see Figure 15, is easy to see how the battery system works. It charges from the mini-grid when the demand is low. It stores up to 6.72 kWh that can be supplied whenever the demand reaches a point that cannot be covered by the generator of the GP. As it is not a principal demand it would be consuming in low-demand time periods there is no problem about load.
After stating all the demand that will be loading the mini-grid, few uncertainties arise, and so, the following explanations are done in order to clarify those possible doubts;

- The demand of the community and household segments are not overlapping because, as it is understood by the researchers, the main demand of these two groups occurs in different time laps, and both groups are including the same people but performing different activities. E.g. the owner of a micro-business is demanding the household supply when he/she is not demanding for his/her business.
- During the harvesting season, when the productive uses are in its maximum demand of electricity, the members of the community should be aware of using less energy, so the productivity is not affected.

In the table below, see Table 17, a summary of the demand assessment is shown. As previously stated, it is important to understand that not all the demand is coincident on time, and the responsible consumption must be a remarkable point highlighted to locals when implementing the system into the village.
II. Mapping the Area

The area of the Sekanyonyi village, where the GP pilot plant is to be placed is shown in the Figure 16. The highlighted elements on the picture are the main delivery points of electricity; those are placed regarding the location of the potential users of the energy. The placement of these spots is estimated under the criteria of the researchers due to the lack of exact information. It might not be the actual distribution but for the purpose of the study it can be used as an example of how to develop the mini-grid design. The snapshot is taken from the software “Google Earth”; the distances and the line distribution are also based in the information available in this software. The incapacity of accessing another mapping tool forced the authors of the thesis to take advantage of this tool.

When looking to the Figure 16, six different elements can be found. Amongst those, the customers defined in the previous part can be found. These groups conform as well the backbone of the village, and all are represented in the data collected during the field trip. Also, the GP and a key spot for the mini-grid distribution are included. In the Figure 19 is easy to see that the lines are located all along the roads and paths that connect the different households and parts of the village, this is made in order to facilitate its installation and its access in case of failure.
A description of each of the elements is done below.

- **The Green Plant**: It is the source of the energy. The placement of the GP has been selected regarding its functioning and concept. As an industrial activity is being carried out in it, the fact that noise and other disturbing factors are likely to happen pushed the location of the GP away from the inhabited area of the village.

- **Sekanyonyi Centre, key distribution spot**: It is one of the main points in the distribution line. The mini-grid is spread around the village, and this middle point is the perfect location to set a distribution position to reach the rest of the elements in the grid. Also, taking in account the possibility of expanding the grid over time this point gives an advantageous situation.

- **Trade Centre & Grocery Store**: These two points situate the two stores that are in the village; they are separated so they cover a greater area regarding the service provision. The given names are different so it is easy to distinguish them.
• **School 1 & 2**: The two schools that are in the village. As the stores, the fact that those facilities are dispersed reduces the distances that most of the kids have to cover.

• **Cluster 1,2,3,4,5 & 6**: The clusters refer to the household groups. The fact that it is not possible to know which households will or not be connected to the mini-grid since the beginning, forces to use this kind of method. The mini-grid will reach these distribution points named clusters and then, the households that wish and are prepared will be easily able to connect to the distribution line. The number of households per cluster is defined in Table 18.

<table>
<thead>
<tr>
<th>Cluster nº</th>
<th>Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>25</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>25</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>10</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>8</td>
</tr>
<tr>
<td>Cluster 5</td>
<td>7</td>
</tr>
<tr>
<td>Cluster 6</td>
<td>35</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>110</strong></td>
</tr>
</tbody>
</table>

This distribution is made according to the position of each cluster in the map. Cluster 6, as is the most centric, is the one surrounded by more households, and so, it is the one that is more likely to serve more customers. The same logic has been applied to the consideration of the rest of the groups. Another factor that affected to this decision was the fact that the longitude of the line, which is connecting cluster 6, is shorter than the rest but the one to cluster 5. And this issue is relevant when calculating the line size and the conductor, and so, directly related to the budget.

• **Productive Activity**: The productive activity area is related to the industrial and agricultural activities. It is placed beside the GP to reduce losses in electricity transmission and separated of the urban area for the same reasons than the GP.

### III. **System Layout**

The distribution of maximum loads of the system, the distances within the delivery lines and the overview of the mini-grid are explained in this stage of the design. It is useful to have a conceptual outlook of the system and to understand how to approach the steps of the design as the selection of the conductors, the sizing of the lines or the implementation of the poles, those further technical stages are exposed in the Appendix VIII.

The evaluation of the coincident loads among the customers and the lines needs to be assessed, and as it is done in the first stage of the design, a table related to the layout with the relevant data of the system is shown next, see Table 19.
Table 19. Distribution of Mini-Grid Lines and Coincident Load per Line

<table>
<thead>
<tr>
<th>Line</th>
<th>Start</th>
<th>End</th>
<th>Peak load/line (kW)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>Green Plant</td>
<td>Sekanyonyi Centre</td>
<td>10</td>
<td>0.37</td>
</tr>
<tr>
<td>1</td>
<td>Main line</td>
<td>Grocery Store</td>
<td>0.78</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>Sekanyonyi Centre</td>
<td>Cluster 1</td>
<td>2</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>Sekanyonyi Centre</td>
<td>School 1</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>3.1</td>
<td>School 1</td>
<td>Cluster 3</td>
<td>0.8</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>Sekanyonyi Centre</td>
<td>Trade Centre</td>
<td>0.78</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>Sekanyonyi Centre</td>
<td>Cluster 2</td>
<td>3.34</td>
<td>0.1</td>
</tr>
<tr>
<td>5.1</td>
<td>Line 5</td>
<td>School 2</td>
<td>1.34</td>
<td>0.3</td>
</tr>
<tr>
<td>5.2</td>
<td>School 2</td>
<td>Cluster 4</td>
<td>0.64</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>Green Plant</td>
<td>Cluster 5</td>
<td>0.56</td>
<td>0.34</td>
</tr>
<tr>
<td>7</td>
<td>Green Plant</td>
<td>Productive Activities</td>
<td>7.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The lines defined in Table 19 are the ones that can be seen in the Figure 16. As mentioned, the distances are defined according to the data in the software used. The peak-load/line defined is the maximum energy that could pass through each line; thus, this maximum load will establish the base for the technical development of the mini-grid done in Appendix VIII.

In order to fill in the Table 19 with the appropriate coincident load per line, a more deep analysis is done looking directly to the coincident load per user, gathering users per lines, and finally evaluating the coincident load per line of distribution. This is shown below; see Table 20 and Table 21.

Table 20. Maximum Coincident Load per Cluster

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Nº Households</th>
<th>Coincident load per cluster (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>25</td>
<td>2000</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>25</td>
<td>2000</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>8</td>
<td>640</td>
</tr>
<tr>
<td>Cluster 5</td>
<td>7</td>
<td>560</td>
</tr>
<tr>
<td>Cluster 6</td>
<td>35</td>
<td>2800</td>
</tr>
</tbody>
</table>

The assessment of the loads is done according to the data from Table 16 and Table 20. The Table 21 is filled in with the data from Table 17 and Table 18.

Table 21. Maximum Coincident Load per Activity

<table>
<thead>
<tr>
<th>End user</th>
<th>Coincident load per user (W)</th>
</tr>
</thead>
</table>

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Finally, a conceptual scheme, with the line distribution, is done to facilitate the understanding of the line system, see Figure 17. Under the maximum load, the main line will have to bear 10 kW, as it is the maximum supply of electricity at mini-grid disposal. A critical doubt that could appear is related to the battery charging system. It is not counted in the maximum coincident load per line because it would not change anything. There are three distribution lines that go out of the GP, and so, as the maximum load that the GP and the batteries could have is 12.2 kW, and the maximum load of the three lines is 18.06 kW (Line 1, Line 6 and Line 7), the electricity can be distributed through the different lines to avoid possible problems. The design assumes as well that the 10 kW include the telecom tower, as it could be connected to the Line 1.

![Figure 17. Conceptual Schema of the Line Distribution](image)

The feasibility of this system is highly dependent on the basis that has been explained in other parts of the research. The energy source capacity is limited to 9 kW, and so, it is very important to remind that the electricity consumption is tightly related to the season (agricultural means), to the day period (community load and household) and the responsibility of the consumers to not demand high amount of energy when is not
recommended.

The rest of the relevant calculations and the processes carried out in order to have a more detailed view of the mini-grid design are exposed in Appendix VIII. The reason of doing so is based in the fact that the budget conformation would be extremely inaccurate otherwise.

The final conceptual design of the mini-grid after all the calculations done in the Appendix VIII is shown in the Figure 18.

![Figure 18. Final Conceptual Diagram of the Mini-Grid, Lines and Loads](image)

<table>
<thead>
<tr>
<th>B. Battery Charging Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>The battery charging station (BCS) is one of the applications, which are aimed to cover the basic needs of the community by the electrification. As it has been discussed before, there are several examples on this issue. However, this application aims to improve those existing models and modify it in a better and more sustainable way. Hence, the product provides a sustainability approach in terms of environmental and economical aspects and promises improvements on social conditions. The overall benefits could be listed as follows, see Table 22 for the community level approach and Table 23 for the productive uses.</td>
</tr>
</tbody>
</table>

Table 22. BSC Potential Life-Solutions and Benefits for the Community and Household Level

<table>
<thead>
<tr>
<th>COMMUNITY AND HOUSEHOLD LEVEL</th>
<th>Life-Solution</th>
<th>Benefits</th>
</tr>
</thead>
</table>

63
### Lighting

**Time efficiency**: Providing lighting could save time of gathering other possible light sources as firewood or kerosene. Another time-saver comes after the chance of working or doing home-tasks after the natural light is gone.

**Productivity increase**: The possibility of working longer hours and more easily. Clear and instant lighting could improve community conditions allowing the implementation of communal productive activities.

**Educational progress**: Kids and adults can read and improve their educational level in community areas provided with lighting. They could have after school lessons in a shared house with lighting.

**Improved security**: Street or communal lighting could provide security during night-time due to the increase on illumination; robberies or burglaries could be reduced or more likely spotted.

**Richer social life**: The lighting of commune areas would activate social activities and the likeliness of sharing the free time, strengthening the relationship between community members.

**Health improvement**: The possibility of reducing the kerosene lamps, or other lighting devices that mean combustion of any fuel, would directly affect the quality of indoor air.

### Battery Charging

The local people would not have to go to other villages to charge the batteries of the different devices like phones, radios or any other. It would imply timesaving as well.

### Leisure time

The capacity of spending the leisure time in better conditions, increasing comfort and giving the chance of using electronic devices as radios or televisions, which at the same time can help to be aware of political, social or any other kind of events.

---

**Table 23. BSC Potential Life-Solutions and Benefits for the Productive Use Level**

<table>
<thead>
<tr>
<th>Life-Solution</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Opening business longer time, after sunset could increase revenues of shops and home small-scale businesses.</td>
</tr>
<tr>
<td>Electricity Power</td>
<td>Possibility of working with better and more equipment e.g. beauty salon e.g. hair cutting machine</td>
</tr>
</tbody>
</table>

The battery charging system has two main components. The first one is the rectifier, which is an electrical device that converts alternating current (AC) to direct current (DC). The rectifier converts AC, the generator current, to DC in order to charge the batteries. The second device is coming right after the rectifier, the charge controller. This equipment is used to ensure that the system is working, and protects it against possible overloads (in order to protect the batteries and the generator). The costs of rectifiers are dependent to the specification and the design of the device; it means that for different output power and ampere the cost may vary. In this case, the authors have desired to be
able to charge 6 batteries at the same time. The capacity with 1 or 2 batteries would cause bottlenecks in the system and having a large capacity would be too costly for a small village and cause the idle costs. Hence, the rectifier is designed to supply 6 batteries at the same time with an output of 72V and 15A. The supplier has given the price of the desired device as 340 USD.

The battery charging station business model is conceptualized to serve any battery owner from or outside of the pilot village. However, due to budget constraints and in order to be more economical efficient, the start up design is assumed to run with 30 household members from the village. One regular car battery costs approximately 100 USD (the cost is expecting to be decreased by having a battery manufacturer partner). So, the battery purchase will be 3000 USD in total. Of course the foreigners will be able to use the station during the starting up period. For a better understanding of the system a diagram shows the concept of the BCS, see Figure 19.

![Figure 19. Conceptual Diagram of the BCS](image)

**C. Heat Pipe Exchanger**

One of the main objectives of the project is to help the local people to cover their needs, to improve their current life-solutions or to add value to its agricultural harvest, and in doing so, if it is possible, re-use a waste of energy providing a more sustainable approach to the concept. Chasing this purpose, the application that is described below fulfills the requirements, at first sight. In order to have a better and deeper knowledge of the real capacity and potential of heat pipe exchanger a detailed analysis has been performed. It is covering the design of the application, ending with the evaluation of the likely impacts on the local population.

As a previous overview, two characteristics that describe the benefits that the system could bring are stated:
• **Speed up drying process**: applicable only for the coffee drying process. Currently, this process is done by natural ways: sun drying. The drying process by heat pipe system is expected to decrease the drying process time and also eliminate the process disturbances due to the weather conditions such as rain.

• **Capacity of forecasting drying time and planning the rest of the processing**: the duration of the process is directly related to the weather conditions. However, by applying this system, it is possible to reach a more certain drying process. This opportunity would allow the agriculture cooperative to forecast the production activities and provide to maintain better relationship with the customer in terms of delivery time and amount.

The design of the heat pipe exchanger, as well as its characteristics and working specifications, are given by the supplier’s particular design. The main work done in this stage has been to adapt the device to the GP working conditions, trying to maximize the benefits and seeking to obtain the best results for all the stakeholders. In order to know which device was the more appropriate for the purposes seek by the researchers and the application success, the sizing of the machine capacity had to be assessed. As it is obvious, greater capacity means greater cost, and so, the equilibrium between those two elements is the basic starting point for the selection of the best equipment. All the calculations related to the sizing of the machine can be found in the Appendix IX.

The result of the calculations performed in the Appendix IX is that the device selected is the model CC200. A key point is that 2 devices will be applied in order to achieve a high level of efficiency; obviously this affects significantly the budget and the possibilities of an actual application in the future. The characteristics of the device can be found in the Appendix V. The Table 24 shows the most relevant working specifications.

<table>
<thead>
<tr>
<th>Supplier and Model</th>
<th>Noren CC2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Capacity</td>
<td>2.19 kW</td>
</tr>
<tr>
<td>Electricity Consumption</td>
<td>44.26 kWh/year</td>
</tr>
</tbody>
</table>

The main idea of this application is to recover the waste heat inside the GP container and stream it inside a room where the coffee seeds will be stored, in that way, speed up the drying timing, reduce the process and allow the prevision of the next steps in the coffee procedure. The figure below, Figure 20, shows a conceptual overview of how the system would work.

The conduct to stream the heat source is dependent on the distance between the heat source (GP) and the drying chamber. The possibilities to cover this tubing system are varied, since the application of thermally insulated pipes to the use of PVC, or other plastic tubes, previously covered with a special material that reduces the heat loss significantly. The economical cost of the piping is not going to be relevant when
compared to the cost of the 2 devices needed for the application. So, it is decided not to include into the final budget.

![Conceptual Diagram of the Heat Pipe Exchanger Device Functioning](image)

**Figure 20. Conceptual Diagram of the Heat Pipe Exchanger Device Functioning**

In this analysis there is a key point that is not mentioned until now, it is the system boundary of the container space. As the volume of the gasification machinery that is going to be inside the container is not known yet, the development of this application is done without taking in account that fact. Despite of this, the data related to the volume of the heat pipe exchanger device is included in the brochures that can be found in the Appendix V.
5. Results

The Results section of this work is where the ultimate conclusions of the whole research process are exposed. As stated in the section 3 Methodology, this part is divided into 3 main sections. Each of section forms one step of the last stage of the work. The processes that are included in every sub-section are shown below; see Figure 21.

![Diagram of Results Chapter Development. Sections and Sub-sections](image)

The schema (Figure 21) exposes all the procedure that is carried out to get the final output. In order to be clear, first, the potential applications are selected, and then, the tools in the section 5.2 (Potential Impact Identification of the Selected Solutions), are applied one by one for all the applications. The section 5.3 Final View of the System is the output of merging the different applications all together in the same system.

5.1 Selection of Possible Solutions – MCDA

The MCDA is the key decision making process of the research. The approach is used in order to compare fairly the different solutions exposed. All the possible applications are analyzed with the MCDA. To apply successfully the method for each solution a
spreadsheet table is prepared. The table consists of the potential applications and the criteria related to them (including the weight for each criterion). An overview of the possible market solutions is done to find reliable data of the different applications regarding market issues as the economical costs or the working conditions. The brochures and descriptions of the chosen options are shown in the Appendix V.

The previously mentioned spreadsheet chart has been fulfilled in order to perform the decision-making calculations. The approach is explained more detailed in the methodology part (3.1 Selection of Possible Solutions – MCDA) and a useful example is given in the Appendix IV. A layout of the starting chart can be seen in Figure 22.

<table>
<thead>
<tr>
<th>Potential Solutions</th>
<th>Criteria</th>
<th>Economical Cost (USD)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial investment</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>0,15</td>
<td>0,15</td>
</tr>
<tr>
<td></td>
<td>New Business Opportunity</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td></td>
<td>Population coverage (%)</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td></td>
<td>Electricity consumption (kWh/y)</td>
<td>0,05</td>
<td>0,05</td>
</tr>
<tr>
<td></td>
<td>Environment Care</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lifespan (years)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 22. Initial MCDA Chart**

This chart is the main tool used for the MCDA process. The blank cells are filled with the information taken from the brochures together with the data extracted out of the section 4.3 Pilot Area and 4.4 Applications and Life-Solutions. In the Appendix VII can be found a summary of the relevant data used for each application, as a result of merging the sub-sections previously mentioned.

**Weighting the Criteria**

The weights of each criterion have been decided according to the discussion sessions which have been performed between the authors and the members of Pamoja.
Cleantech AB. The aim was to feature all the three aspects of the sustainability. The authors tried to value the criteria as equally as possible. In conclusion, the economical and environmental aspects are the distinctive ones along with the new business opportunity criterion.

Once the aforesaid data is added to the previous chart, it is time to analyse the results. In the next chart, see Figure 23, the cells are filled appropriately. It is clear that, as mentioned in the section 3.1 Selection of Possible Solutions – MCDA, some of the criteria cannot be assessed by an absolute value, then it is given a relative value, which is equivalent to the comparison of all the applications for the same criteria; from the best(s) that is given a 10, down to the middle(s) with a 5 and ending with the worst(s) given a 1. The chart is not ranked or it shows at first sight any conclusion. The chart is used as a matrix that has to be mathematically operated, and just after this the ranking can be extracted.

<table>
<thead>
<tr>
<th>Potential Solutions</th>
<th>Criteria</th>
<th>Weight</th>
<th>Economical Cost (USD)</th>
<th>Economical Gross Benefit for Pamoja</th>
<th>Development empowerment</th>
<th>New Business Opportunity</th>
<th>Population coverage (%)</th>
<th>Electricity Consumption (kWh/y)</th>
<th>Environmental Care</th>
<th>Lifespan (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Biochar Application</td>
<td>0,2</td>
<td>1</td>
<td>0,1</td>
<td>0,15</td>
<td>0,1</td>
<td>0,1</td>
<td>0,2</td>
<td>0,05</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Battery Charging system</td>
<td>0,1</td>
<td>340</td>
<td>No Data</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>70</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>Mini-grid</td>
<td>0,1</td>
<td>9700,00</td>
<td>5 years free warranty and optional prolong</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>90</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>Heat pipe Exchanger</td>
<td>0,15</td>
<td>2820,00</td>
<td>5 year warranty 73.93 USD cost</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>63,63</td>
<td>44,6</td>
<td>10</td>
</tr>
<tr>
<td>E</td>
<td>Recuperator</td>
<td>0,1</td>
<td>NO APPLICABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Absorption Chiller</td>
<td>0,1</td>
<td>4518,26</td>
<td>No data</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>100</td>
<td>518,4</td>
<td>5</td>
</tr>
<tr>
<td>G</td>
<td>Organic Rankine Cycle Turbine</td>
<td>0,1</td>
<td>15000,00</td>
<td>No warranty Likely failure</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>80</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

*Figure 23. MCDA Chart with Values*
There are two key factors that have to be highlighted to avoid leading to confusion.

1. The fact that 1 is the lower valuation for all the criteria is due to the fact that 0 cannot be included in the mathematical calculations.

2. Two of the criteria that can be assessed with absolute values need special treatment. In the case of “Economical Cost” and “Electricity consumption” as higher is the value, the worse is the application; this is the opposite reasoning than the used in all the rest of criteria. This is corrected by a modification in the mathematical procedure, switching up the values in the ratio.

Once the mathematical operations described in the example, see Appendix IV, are applied in this case with the data given the results are the ones shown below, see Table 25.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Value</th>
<th>Comparison</th>
<th>Final Ranking</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>R(A/B)</td>
<td>2,475717592</td>
<td>A &gt; B</td>
<td>1</td>
<td>A – Biochar</td>
</tr>
<tr>
<td>R(B/C)</td>
<td>1,76189639</td>
<td>C &gt; B</td>
<td>2</td>
<td>C – Mini-Grid</td>
</tr>
<tr>
<td>R(A/C)</td>
<td>3,641242949</td>
<td>A &gt; C</td>
<td>3</td>
<td>B – Battery Charging System</td>
</tr>
<tr>
<td>R(C/D)</td>
<td>1,57232776</td>
<td>C &gt; D</td>
<td>4</td>
<td>D – Heat Pipe Exchanger</td>
</tr>
<tr>
<td>R(C/F)</td>
<td>4,067583517</td>
<td>C &gt; F</td>
<td>5</td>
<td>G – ORC Turbine</td>
</tr>
<tr>
<td>R(C/G)</td>
<td>1,61118058</td>
<td>C &gt; I</td>
<td>6</td>
<td>F – Absorption Chiller</td>
</tr>
<tr>
<td>R(B/G)</td>
<td>2,369696748</td>
<td>B &gt; I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(B/D)</td>
<td>2,312552686</td>
<td>B &gt; D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(D/G)</td>
<td>1,024710383</td>
<td>D &gt; I</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Table 25 shows the relative value of one application to the other, and so, having these measures for all the applications allows the creation of the ranking that prioritize the potential applications regarding the criteria chosen and its importance for the research. Thus, the selection of the potential applications is defined below; see Table 26.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Status</th>
<th>Main Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar</td>
<td>1st</td>
<td>No initial cost. Covers entire agriculture cooperative. Highest environmental care</td>
</tr>
<tr>
<td>Mini-grid</td>
<td>2nd</td>
<td>Major economical benefit for Pamoja. Highest development and business creation opportunities. Rural electrification solution.</td>
</tr>
<tr>
<td>BCS</td>
<td>3rd</td>
<td>Economical benefit for Pamoja. Low initial cost. Minor rural electrification solution. Minor development and business creation opportunities.</td>
</tr>
<tr>
<td>Heat Pipe Exchanger</td>
<td>4th</td>
<td>High environmental care. Minor development and business creation opportunities.</td>
</tr>
</tbody>
</table>
Some conclusions can be extracted from this last procedure and its results. The reason of why biochar is the first alternative is mainly about the economical aspect. The application does not have any initial cost and it has one of the two highest environmental care grades. The economical and environmental criteria are the two with highest weight. Hence, they affect the result more than the others. On the other hand, the advantage and strength of the mini-grid application as second product, is coming from its high potential of economical benefit, development empowerment and business opportunities. Besides, the application itself covers 90% of the population. The last two selected options, the BCS system and heat pipe exchanger application, have common characteristics. The main difference between the two solutions is derived from the economical benefit, where the BCS has a higher grade.

Despite of the great result that biochar obtained in the MCDA, the design of the biochar is not developed, as there is not a system as itself. The impacts are pretty unknown and have been described in the section 2.3.1 Biochar Application. The rest of the applications’ development is done below. The development of the work, as shown in Figure 21, is done section by section, where the three selected solutions are analyzed before moving forward to the further sub-section.

In conclusion, four applications are to be developed and designed. The development of the selected solutions is done in the following parts, based on the data collected and analyzed in the previous sections and in this assessment.

### 5.2 Potential Impact Identification of the Selected Solutions

Despite that it could appear needless to say, all the new and innovative installations have some consequences. Hence, in order to maintain the projects, environment and social issues, it is crucial to assess the potential impacts of the actions. However, the estimation of these changes is not easy and it is based on the current global situation, the key factors detected by the researchers and the future evolution of the area.

In this section of the work, it is intended to identify and highlight which are the potential impacts related to the implantation of the selected applications. As the effects that are relevant for the research can be divided between environmental, social and economic, this section will be divided in the same parts. The work done by Vanclay (2003), Bruhn & Eklund (2002), Ecaat (2004), and others has been used as inspiration; the approaches given by these mentioned authors have been used as guide and baseline, although the profundity of the analysis carried out in this report is not comparable with the one reached by the cited researchers.
Social Impacts
The first step must be to define what is understood for social impacts; a definition can be extracted from a description of Vanclay (2003), the social impacts are;

“...the intended and unintended social consequences, both positive and negative, of planned interventions and any social change processes invoked by those interventions...”

Now that it is clear what is understood as social impact, it is the moment to define which steps will be done in order to identify them. The steps for the analysis development are taken from the Guidelines and Principles for Social Impact Assessment (The Interorganizational Committee on Guidelines and Principles for Social Impact Assessment, 1994), and are the following:

i. Baseline study: describe the area and define the human environment. The data can be taken from the section 4.3 Pilot Area and 4.4 Applications and Life-Solutions.
ii. Identification of the stakeholders in the area: social, economical, cultural and environmental facts related to stakeholders activities.
iii. Identify the major impacts or the most likely possibilities within it.
iv. Identify and anticipate the social impacts and possible reactions.

The main instrument used to execute the analysis is the field observation. The use of the data collected during the field trip, the connection with Pamoja Cleantech AB and the rest of stakeholders is the tool that will bring useful and reliable information to, according to the steps defined before, complete the analysis. Regarding to the appliance of this method as results, the points i) and ii) are common for all the selected applications, on the other hand, the impacts detected will be directly dependent to the application under study.

Environmental Impacts
The environmental impact identification objective is to assess the environmental impacts associated with the implementation of the GP in a specific area, as well as taking in account the sustainable development matters related to those impacts. Therefore, the developers of the GP can prevent and foresee which are the main future potential problems, and so, avoid them by modifying the project (Bruhn & Eklund, 2002). Specially, the environmental impact is important and worth to analyze because there is not much industrial activity in the area. Plus, the main economical activity in site, agriculture, is tightly dependent on environmental conditions. The development of the followed methodology is based on the guidelines and procedures stated in the Review of the Application of Environmental Impact Assessment (EIA) in Uganda (Ecaat, 2004), see Figure 24.
To have a clear idea of which are the possible impacts included in the analysis, ecological and social issues have been stated below as in Kakuru, et al. (2001), see Table 27.

**Table 27. Environmental Aspects Included in the Analysis (Kakuru, et al., 2001)**

<table>
<thead>
<tr>
<th>Biological Diversity</th>
<th>Effect on number, diversity, breeding habits, etc. of wild animals and plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gene pool of domesticated plants and animals</td>
</tr>
<tr>
<td>Sustainable Use</td>
<td>Effect of proposal on soil fertility</td>
</tr>
<tr>
<td></td>
<td>Breeding populations of fish and game or wild animals</td>
</tr>
<tr>
<td></td>
<td>Natural regeneration of woodland and sustainable yield</td>
</tr>
<tr>
<td>Ecosystem maintenance</td>
<td>Effect of proposal on food chains</td>
</tr>
<tr>
<td></td>
<td>Nutrient cycles</td>
</tr>
<tr>
<td></td>
<td>Aquifer recharge. Water run-off rates, etc.</td>
</tr>
</tbody>
</table>

As conclusion of this part, it is important to state that Environmental Impacts Identification output have to be taken as a strategy in order to prevent and compensate the potential ecological damage produced by the project development. Therefore, avoid the possible harm to the environment that is not just the community base, is also one of the most important collaborators related to the success of the project.

**Economical Impacts**

The economical impact description, according the definition of Weisbrod & Weisbrod (1997), is:

“Economic impacts are effects on the level of economic activity in a given area”

However, this is a very general and non-specific definition. So, in order to clarify what is
exactly understood by economical impact, the main points analyzed in this study are going to be described one-by-one. The selection of these following points has not been random or stochastic, but according to its economical coverage, the objective of the research and, at last, trying to give an understandable view of the effects that the project can bring to the economical activity into the area (Weisbrod & Weisbrod, 1997).

To easily perform the analysis, the steps to be followed are, a conceptual approach is shown in Figure 25:

i. Define which is going to be the area affected by the implementation of the project, the borders of the analysis. The **Area of Influence** is the area of the village where the cooperative is placed, and where the jobs opportunities and the “revenues” of the project will affect.

ii. Identify and analyze the direct and induced effects that are going to be assessed.

   - **Total Employment**: the increase of number of jobs created after the economic growth due to the implementation of the project.
   - **Value Add**: the sum of: individual income increase and the economical benefit of the company.
   - **Induced Effects**: the impacts to be accounted as a spending in electricity or willing to pay due to an estimate increase in local people economic level.

iii. Conclude which are the estimated economical impacts of each of the scopes researched.

---

**Figure 25. Potential Economical Impact Identification Procedure**

Even though these impacts appear to be easy to assess there are a few drawbacks that must be regarded during the analysis.

- **Total Employment**: The accounting of job creation does not imply that the job opportunity is being increased too, and that it cannot be compared to the public cost of creating these jobs, meaning subsidies, public grants, etc.
- **Value Add**: includes all company benefits, even though some of these revenues will not have any impact in the area under study. Some of this wealth can be invested out of the region of influence.
As conclusion for this part, it is easy to state that economical assessment can be useful in order to have an idea of big figures, general numbers and to estimate which are the paths that can be used to help the local economy growth; but, to evaluate how these elements can affect the daily life of the locals there is the need of a deeper analysis, the disposition of specific detailed data and the exact budget involving all project development.

Finally, after all the applied methodology is explained, the analysis of the potential impacts for the mini-grid starts below.

A - Mini-Grid
   a. Social Impacts
      i. Baseline Study
      The baseline study is based in the data relevant to describe the human, cultural, economic and environmental state of the area that is being researched. The use of the sections 2 The Green Plant Concept, 4.3 Pilot Area and 4.4 Applications and Life-solutions, is basic for this stage. Although, there is a lack of information from the field trip that could be useful and interesting for this study, e.g. gender equality, workload per age, adults/kids or male/female work ratio, etc.
      The idea of this first point is to describe the starting point situation of the community, so the changes that can happen, the impacts, can easily be identified. Thus, it is of much importance to portray as actual as possible a big picture of the community. The following tables will help to understand which the relevant points for the analysis are. The tables can be classified according to its topic, social issues, agricultural facts and energy consumption levels. The first tables are related to the current social situation of the village; see Table 28 and Table 29.

Table 28. Energy Issues Related to the Current Community Situation

<table>
<thead>
<tr>
<th>Community Current Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
</tr>
<tr>
<td>110 households</td>
</tr>
<tr>
<td>880 people (approx.)</td>
</tr>
<tr>
<td><strong>Area of the Village</strong></td>
</tr>
<tr>
<td>The village is spread along 6 km²</td>
</tr>
<tr>
<td><strong>Schooling Rate</strong></td>
</tr>
<tr>
<td>8 schools in the area (2 reachable for mini-grid)</td>
</tr>
<tr>
<td>High schooling among kids</td>
</tr>
<tr>
<td><strong>Active Local Organization</strong></td>
</tr>
<tr>
<td>Magara Cooperative</td>
</tr>
<tr>
<td>3 years of work experience</td>
</tr>
<tr>
<td>The coop. work increases social and economical possibilities among the community</td>
</tr>
<tr>
<td>2 Small-business (Grocery Stores) working in the area</td>
</tr>
<tr>
<td><strong>National Grid</strong></td>
</tr>
<tr>
<td>Not connected and not planned in long time period</td>
</tr>
</tbody>
</table>

Table 29. Social energy Concerns

<table>
<thead>
<tr>
<th>Energy Issues Related to Community</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
Energy Concern | Diesel price and lighting possibilities  
| Productivity - Not expanding possibilities due to energy lack

Desirability in the use of energy | Ranking among community what would be the uses of energy  
| 1 – Lighting  
| 2 – Agricultural machinery.  
| 3 – Charging phones  
| 4 – Beauty Salon  
| 5 – Refrigeration for food storage

The following tables show the energy situation in the region at this time; Table 30 and Table 31.
Table 30. Energy Use in the Household Level

<table>
<thead>
<tr>
<th>Cooking Use</th>
<th>Meals per day</th>
<th>3 meals total</th>
<th>Breakfast 0.5 hours</th>
<th>Lunch 2 hours</th>
<th>Dinner 2 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time per meal</td>
<td>4.5 hours total</td>
<td>4.5 hours total</td>
<td>0.5 hours</td>
<td>2 hours</td>
<td>2 hours</td>
</tr>
<tr>
<td>Energy need</td>
<td>3 firewood pack per day for cooking the meals</td>
<td>3 firewood pack per day for cooking the meals</td>
<td>10 litres per household per day</td>
<td>10 litres per household per day</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>Rooms lighted</td>
<td>5 rooms</td>
<td>5 rooms</td>
<td>5 rooms</td>
<td>5 rooms</td>
</tr>
<tr>
<td>Time lighted</td>
<td>5 hours average</td>
<td>5 hours average</td>
<td>5 hours average</td>
<td>5 hours average</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>Micro-solar cell</td>
<td>Phone charging</td>
<td>Phone charging</td>
<td>Phone charging</td>
<td></td>
</tr>
</tbody>
</table>

Table 31. Energy Current Situation, Use of Energy at all Levels

<table>
<thead>
<tr>
<th>Energy Current Situation</th>
<th>Type</th>
<th>Price</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Current Sources</td>
<td>Kerosene</td>
<td>1.06 USD/litre</td>
<td>Lighting</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>1.06 USD/litre</td>
<td>Agriculture productivity</td>
</tr>
<tr>
<td></td>
<td>Firewood</td>
<td>0.35 USD/pack</td>
<td>Cooking &amp; lighting</td>
</tr>
<tr>
<td></td>
<td>Charcoal</td>
<td>5.33 USD/bag</td>
<td>Cooking &amp; lighting</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Kerosene</th>
<th>2.5 litre/household*week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diesel</td>
<td>70 litre/week (harvest 4 peak months/year)</td>
</tr>
<tr>
<td></td>
<td>Firewood</td>
<td>3 pack/day</td>
</tr>
<tr>
<td></td>
<td>Charcoal</td>
<td>260 kg/month (4 bag/month)</td>
</tr>
</tbody>
</table>

And finally, the last two tables make reference to the productive or the economical activity in the area; Table 32 and Table 33.

Table 32. Current Cooperative Productivity

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Coop. members</th>
<th>Production</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>70</td>
<td>3 acres/member</td>
<td>140,000 kg/year</td>
</tr>
<tr>
<td>Coffee</td>
<td>73</td>
<td>1 to 4 acres/member</td>
<td>47,600 kg/year</td>
</tr>
<tr>
<td>Beans</td>
<td>68</td>
<td>1.5 acres/member</td>
<td>2,800 kg/year</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>20</td>
<td>0.5 acres/member</td>
<td>No data</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td></td>
<td>100 liters/day</td>
</tr>
</tbody>
</table>

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Table 33. Machinery Power and Energy Use

<table>
<thead>
<tr>
<th>Machine</th>
<th>Power</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel generator</td>
<td>9.7 kW</td>
<td></td>
</tr>
<tr>
<td>Maize mill</td>
<td>7.5 kW</td>
<td>400 kg/day</td>
</tr>
</tbody>
</table>

Energy Consumption for the Machinery

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fuel</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Generator</td>
<td>Diesel</td>
<td>10 litres/day</td>
<td>1.06 USD/litre</td>
</tr>
</tbody>
</table>

Other relevant points:

- It is important to understand that a member of the cooperative means a household associated to the cooperative system.
- When there are impacts that are affecting the production of the cooperative, there are two kinds of impact on population: direct (workers, mainly men) and indirect (households that are economically dependent on cooperative activities, women and kids).
- Even though there is no access to electricity in the area, comparing the price of electricity grid 550 UGX/kWh, to the estimate price the GP could provide is also of much importance to realize the level of the impact it is causing.
- The output of maize milling, called “posho”, supposes one of the main basic elements in local’s diet.
- The cooperative has at its disposal a piece of land that could be used for the implementation of the GP.
- Milk storage is one of the main issues that the community is facing. Nowadays, there is no way to keep it assuring that healthy conditions are not going to be affected.

ii. Identification of the stakeholders in the area: social, economical, cultural and environmental facts related to stakeholders activities

The stakeholders that can contribute or either be affected by the implementation of the GP are the cooperative and the locals living in the area. The social institutions, as schools, can be subjected to an impact as well. The lack of health-care clinics, hospitals, or other governmental facilities reduce the capacity of having more spread positive impact further than the area that the cooperative covers. Therefore, in order to comprehend which are the stakeholders that can have a direct effect over and after the project, these are listed below.

- Magara Farmers Cooperative.
  The farmer’s cooperative is the main stakeholder for the biomass supply and, as a previewed, should suppose the main consumption of electricity production, so become the main customer for the output of the GP. The cooperative suppose also the principal actor involved in the productive activities in the area. The success of the cooperative is of much importance because most of the families in
the area are dependent on its productivity and market future. There are possibilities of expanding the business and the crops that are currently harvested, and there is a big interest among the members to improve the processes that are possible to carry out in its facilities. Micro-finance options are available for the associates and can bring new advances regarding machinery and accessible amenities.

- Community, citizens of Sekanyonyi.
Obviously, the community is another key stakeholder for the success of the GP project. The community represents the end-user and includes all the households that are also potential consumers. It is also the organism that links all the customers and that intertwine all business, institutions and people in order to interrelate them and sews the social network. It is important to keep it alive to spread the possible positive impacts that the GP can bring.

- Micro-business, run by local inhabitants.
The micro-businesses that are set up in the area, like stores or workshops, are potential customers and the enlargement and improvement of them can bring an increase on economical activity in the area.

Despite of the current stakeholders, there are future possibilities that shouldn’t be discarded, as the implementation of a project like that can bring future business and increase the market opportunities. Regarding the applications defined in previous parts, and the discussions held between the researchers of this work and the Pamoja Cleantech AB promoters, there are a few potential stakeholders that must be taken in account for the assessment.

- Micro-business on refrigeration for food storage
The possibility of having available electricity could enhance the entrepreneurship among the people and one of the main uses of the energy could be to serve a refrigeration system in order to store food products. The storage could be for self-consumption as well as to preserve the products until the moment they are sold.

- Health-care service
A small clinic or a center for health care is missing in the area. The implementation of an energy providing plant could motivate the installation of some services in that direction. Reliability on lighting and on the capacity of store medication would be the key factors.

iii. Identify the major impacts or the most likely possibilities within it
The impacts identified during the whole research process and stated here can be separated into two basic groups, positive and negative impacts. It is important to highlight that those impacts are not the result of a specific process like this, but the
output of the knowledge acquired during a long process that started at the same time together with the research.

Positive:
- Reduction in consumption of expensive fuel. The price of diesel is much higher than the energy supplied by the GP. The exact prices and data regarding this point are explained in the following economical analysis.
- The possibility of reducing the use of kerosene for house lighting will increase the quality of in-door air and so, have a direct positive impact in people’s health.
- The possibility of empowering the area could contribute with enforcement in community strengthening and stimulating collaboration among the members of it; especially in between cooperative members.
- The spread of electricity all along the community would increase inhabitants’ possibilities and with the likely enlarged economical activity, a growth in community consumption of energy.
- The increase on their revenues mean a possible escalation on their consumption, and a directly rise of worker salaries which at the same time means a probable enlargement of household opportunities. Therefore, an increase on social welfare.
- The control on production stages and the improvement of it could mean an increase on leisure time for workers. And so, the involvement of those into social task and life.
- The delivery of electricity and lighting to the households could mean the possibility for the students to do their homework, readings and other educational activities for longer hours and at their own places. Thus, improving educational level in the area.
- Lighting could as well allow the micro-business to work longer hours even though when there is no natural light.
- Social security during night hours in the village would be improved if lighting was to be spread along the area.
- The production improvements would mean potential increase on revenues out of market. At the same time, these revenues could be used to purchase new machinery and increase even more the production of the cooperative.
- The empowerment of agricultural production and activity could mean feeding self-sufficiency, guaranteeing the feedstock and the market possibilities during bad-cropping seasons.
- The lighting and the improvement in community facilities, like schools, motivate the workers and it is more likely that work-absenteeism is significantly reduced.

Negative:
- Possible creation of a need on energy supply. If community starts building their economical and social opportunities around energy, there is the danger of fostering energy dependence.
- The difference in positive impact of energy supply among society could mean unequal future possibilities between who is member of cooperative and who is not. This could lead to social disparity and create conflicts within the people in the area.
iv. Identify and anticipate the social impacts and possible reactions

The possible prevention to reduce the potential drawbacks of the project are defended in this stage. There are two main negative impacts that can potentially affect the development of the project.

- The development of a dependence on electricity or other forms of energy is a harm that must be carefully approached. The focus must be put on creating tools and strategies to prevent these problems, the batteries or the ownership of small solar cells in the future could help the community to keep their energy sovereignty.

- The generation of unequal opportunities among society can be a problem as well. If much of the efforts for the development are focused on increasing the cooperative possibilities, which at first sight is not a bad idea, the people in the area who are not associated to it can feel left aside. Thus, at the same time foster envy and pain, and disparity within community, which could lead to a social break up. The effort should be focus on the enhancement of the society and the provision of different opportunities for all the community, not depending on their initial economical capacity. An example could be, share some crop fields, share batteries or other type of collaborations amongst the locals with less economical resources.

b. Environmental Impacts

One of the basic ideas that must be clear before starting the environmental assessment, is to bear in mind that future generations must not be affected by a possible environmental harm caused by the implementation of the current project. Once, this important statement is clear, the three steps of the assessment can be performed.

Step 1 - Project Identification.

As it had been described in the research, the GP is considered as a “black box”, so the authors of this work are not going to analyze the environmental impact of the GP system, but the output applications. In that case that means the mini-grid application. Thus, just its impacts are going to be assessed and to do so, different examples and reviews of other works have been used (World Bank Independent Evaluation Group, 2008; The World Blank, 2008). The impacts are divided between positive and negative.

Positive

- Reduction in the use of diesel, kerosene and firewood. The first two mean a reduction in CO₂ emissions, the latter a reduction to the stress that the woods around the village are subjected to. The following calculation will show the real saved CO₂ emissions; see Table 34.
Table 34. Reduction of CO2 Emissions

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Consumption 6</th>
<th>CO2 content 7</th>
<th>CO2 kg saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>132.5 litres/year</td>
<td>2.4 kg CO2/litre</td>
<td>318 kg of CO2</td>
</tr>
<tr>
<td>Diesel</td>
<td>1200 litres/year</td>
<td>0.7 kg CO2/litre</td>
<td>840 kg of CO2</td>
</tr>
</tbody>
</table>

- An Energy supply origin from a renewable energy technology source. It means that under sustainability work conditions it should be able to provide energy without problems to future generations.

- A potential future use of electricity for refrigeration means would reduce food waste. Milk, meat together with vegetables could last longer and preserving all organoleptic properties. At the same time, it might be possible that the need of producing milk or meat diminish, so the pressure to which the animals are subjected would decrease.

Negative

- If the dependence on the crop production increases and the market pressure rises, farmers start to feel over-demanded and might apply non-environmental friendly methods to raise their crops. Possible use of chemical fertilizers that could endanger the use of the soil in the future.

- If one crop is pointed as the more efficient for the GP biomass or market purposes, it can result in the implantation of a monoculture crop activity which is completely dependent on market and that at the same time reduces the food sovereignty of the area because all the production is focused on market. Thus, putting in risk feed stock and using a bad agricultural methodology because the monoculture can foster the quick spread of vegetal diseases.

- Intensification of the agricultural methods due to market pressure. There are many drawback of it, mainly are use of pesticides, the soil erosion, the destruction of natural habitats and the high amount of energy inputs to keep a high productivity.

- The mini-grid itself can mean a negative environmental impact, because of its installation and the materials used for the construction of it.

- When using a potential water-pumping application for the use of the energy, the fact that the source of water is irregular and even in few seasons is not available at all and that there is going to be the capacity of extracting it without no physical effort, can lead to the drastic overexploitation of it, and its completely disappearance of the water source.

**Step 2 – Pre-feasibility Assessment.**

The majority of the negative impacts can be successfully prevented with the right environmental related education, with advices and standards of behavior. Not just for

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6 Assuming the consumption rates stated in the previous point of this impact assessment (Section 5.2.3 Potential Impact Identification of the Selected Solutions), Social Impacts

7 Source: Kaufman, 1999
the farmers or the business runners, but for the whole community, because the success of sustainability relies on global conduct. Thus, the feasibility study from the environmental point of view is granted as long as the spread of sustainability advices is appropriately done, and the appropriate measures are taken by Pamoja Cleantech AB.

Step 3 – Project Design.

i. Identify which are the negative environmental problems that could arise in the current design.
   - The possible use of chemical fertilizers that could endanger the use of the soil.
   - The intensification of the agricultural methods. Starting to use transgenic seeds and other dangerous materials in order to improve the yield immediately, but threatening the future generations’ possibilities.

ii. Assess if there is any solution that could avoid this negative impacts.

   The contribution that can be done from one of the main stakeholders of the GP project, Vi-Skogen, is essential since they scope of work is agroforestry management; they are also providing agricultural education and advising over the incorrect management of the soil and the methods used. So, fostering this education should be a decisive tool.

   c. Economical Impacts

   The economical impact assessment must be done based in real data, in the best case the source of information will be the community affected itself, whenever this is not possible other reliable sources of general information will be accessed. The UN and its independent groups as FAO or others must be one of the first databases checked for information. In doing so, some general statistics about Uganda facts are stated in the following table (UNData, 2011; UNICEF, 2011), see Table 35.

   | Economical Facts                                                                 |
|----------------------------------|----------------------------------|
| **GDP (gross domestic product) per capita (USD) and % of growth**                  |
| 2000                             | 256.8                            |
| 2005                             | 346.8                            |
| 2008                             | 500                              |
| Average annual rate of inflation (1990-2009) %                                   |
| 8                                |
| Energy consumption per capita (kilograms oil equivalent)                           |
| 37.0                             |

   Although there is not much quantity of information in the Table 35, it can give an idea of Uganda economic trends. The GDP from 2000 to 2008 has a growth of the 94%, almost double. On the other hand there is inflation that has increased an 8% in 20 years. It is clear that the economical development of the country is beyond doubt, and so, the most likely option is that the trend continues if not at the same rate, at least being favorable to economical expansion. This conclusion, brought to daily life and household
level, means that the average economical capacity of the population must increase and 
so, the will of pay for services and energy supply. It has been not possible to find the 
exact data about wages evolution in the last years, even though this general numbers 
can give an idea of which are the trends also in salaries.

Finally, the information gathered in Table 35, is used in order to have an actual 
knowledge about the economical trends, and so, have a better background to establish 
future potential situations. Also, it allows the researchers to compare the potential 
economical impacts and its repercussions to the current situation. Next, the 3 main 
steps involved in this methodology are performed.

1. Definition of the area under the influence of the project.
The identification of the economical impact starts by defining the influence area of the 
project implemented. In this case, the area of influence is the whole village of 
Sekanyonyi. As the definition of the geographical area is not as important as the 
definition of the economical activities within this village, the main economical activities 
will be stated next:

- Magara Farmers Cooperative (productive and agricultural activities)
- Micro-business (normally owned by particulars)
- Community (basic economical activity)
- Others; temporary workers or transporters

2. Identification and analysis of the direct and induced effects.

- Total Employment
  The direct creation of jobs that the activity produces, by itself, to the community 
it is just valuable during the construction stage, since the working phase does 
not need of any worker to perform properly. On the other hand, defining a 
specific number of new opportunities it is pretty difficult due to the 
uncertainties that are always involved on the new projects in developing 
countries. At first sight, the improvement of processes and the new energy 
scenario should increase the number of jobs in the agricultural industry. In fact, 
the progressive estimated development of the household economy should foster 
people to look for new opportunities as an entrepreneur. It is not possible to 
give a determinate number of new jobs but it is possible to anticipate an 
improvement in the environment that must promote the raising of good 
business opportunities.

- Value Add
  The economical impact that the implementation of the project could have in 
terms of income increase per household is definitely beyond doubt. As it has 
been described through all impact assessment process, the change in 
economical activities due to the availability of electricity will directly influence 
the social income. Like in the previous case, it is difficult to forecast the increase 
on wages but it is possible to assess the impact of improvements affecting the
productivity in the current activities that are ongoing in the area. The economical impact in the coffee processing and the effect on the micro-business and the community usage is assessed below.

- Agricultural Activity: There are two different positive impacts related to the application of the mini-grid into the agricultural activities. First the improvement in coffee processing is assessed. The importance of improving coffee processing is stated in this point. The basic process as husk removal can increase the market price of the product significantly; the Table 36 shows the price difference between the processed or non-processed product.

Table 36. Coffee Price Depending on Processment Level

<table>
<thead>
<tr>
<th>Price of coffee</th>
<th>USD/kg</th>
<th>Coffee condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not processed coffee</td>
<td>0.7875</td>
<td>Raw coffee fruit</td>
</tr>
<tr>
<td>Processed coffee</td>
<td>1.6101</td>
<td>Dried and husk-removed</td>
</tr>
</tbody>
</table>

As it can be seen in the Table 36, the price is more than doubled after the processing. That means that the direct revenues could double the current ones. Using the data regarding production it is possible to see the total increase on revenues that the improvement on the processing would imply. In the following diagram, see Figure 26, an interesting operation has been done. It has been done forecast supposing an increase of production in order to see how much the coffee production should grow in order to equal the benefits between the raw coffee commercialization compared to the processed one.

![Coffee Annual Revenues](image)

Figure 26. Coffee Annual Revenues, Current and Estimated After Processing the Husk

In the Figure 26, the red horizontal line is the revenue of processed coffee with a
steady production based on the actual cooperative productivity (2800 kg). The intersection between the blue and red line marks the production expansion necessary to reach the increase of revenues that the improvements in production would bring. At the same time, the green line shows the rise of income that the processing would suppose. Finally, a production of 5724 kg of coffee would be needed to reach the annual revenue of selling raw coffee compared with processed coffee market.

There is another impact related to the mini-grid application on agricultural activities, it is the difference in the energy cost. The Table 37 shows the difference in the cost for the same activity, the milling. According to the data from the Appendix VIII, the mill needs the supply of energy from an electrical motor that consumes 9.54 kWh working under normal conditions. Therefore, using the data from the section 4.3 Pilot Area and from the Appendix VIII, the result is clear; see Table 37.

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
<th>Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>1200 litres</td>
<td>1.06 USD/litre</td>
<td>1272 USD</td>
</tr>
<tr>
<td>Mini-Grid</td>
<td>8013.6 kWh</td>
<td>0.18 USD/kWh</td>
<td>1442.448 USD</td>
</tr>
<tr>
<td><strong>Annual Cost Difference</strong></td>
<td><strong>170.45 USD</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The conclusion after looking at Table 37 is that there is an increase on the price of the energy, and so, it would suppose a negative economical impact. On the other hand, there is no transport cost or attached pollution. Furthermore, the availability of electricity is supposed to be much more reliable than the diesel because the power point is meant to be right in the mill. Therefore, the balance is neutral, although the price is higher, the mentioned advantages payback the addition in price.

Micro-Business and Community Usage: The implementation of micro-business in the area, or the improvement of them with the provision of electricity, could imply an economic impact among the local population. There are some key factors that show how the implementation of a mini-grid can positively push the creation of entrepreneurship among the community. Nowadays, drawbacks like the lack of light to perform the work adequately, or the possibility of not working enough hours to have the profitability required to hold the business could be eliminated with the suitable energy supply.

As Maleko (2005) states in his work as real examples in Tanzania, locals and entrepreneurs highlight that the access to electricity is one the main elements that motivate the creation of micro-business at local level. The creation of these

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8 According to 7 hour work per 4 peak months a year (120 days/year)
9 Data facilitated by Pamoja Cleantech AB
microenterprises at the same time means creation of jobs and the activation of local economy. Jobs are wages and these salaries are the ones that will hold the entrepreneurs successfully on their business. Quoting one of Maleko (2005) conclusions:

“The availability of the electricity services is one of the factors facilitating the decision of local entrepreneurs to invest in income generating activities such as milling machines, wood works, welding workshops in a specific area because most of these enterprises are found in centers where there is an electricity supply line”

At the same time, the creation of these businesses helped the locals to live more comfortably in their own community and village, as there are more services provided in a close area distances are drastically reduced as well as the time invested on daily tasks.

There is another factor that pushes for the productive use of micro-enterprises, to foster the economical development and the increase on consumption capacity. A small analysis on the load factor of demand has been developed by assuming a household consumption according to the experience from the field trips. First, it is important to define what is the load factor (World Bank Independent Evaluation Group, 2008):

“The load factor is the ratio of average consumption to the total possible consumption”

Now, it is important to define the consumption ratio along the day, and keeping out of the assessment the telecom tower load supply (1 kW). The values of consumption given in Table 38, are an estimation based on the experience from the field trips, the elements included in the Table 58 and the consumption of each of them is according to the assumptions done in the section 4.4 Applications and Life-Solutions, for the mini-grid (Table 16), other data used to support the assumptions made can be found in the World Bank Independent Evaluation Group (2008) and in The World Bank, 2008.
Table 38. Estimated Consumption at Household Level for 24 hours, normal day

<table>
<thead>
<tr>
<th></th>
<th>Lighting for 110 households for 5 hours, from 18:00h. to 23:00h.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NIGHT</td>
<td>1 bulb per household on at the same time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 bulb = 60 W = 0.06 kW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 w x 1 bulb x 110 users = 6600 w = 6.6 kW on lighting</td>
<td></td>
</tr>
<tr>
<td>DAY</td>
<td>Radio for 20% of households for 5 hours, from 10:00h. to 15:00h.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 radio = 5 W = 0.005 kW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22 users x 5 W = 110 W = 0.11 kW on radio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other uses for 7 hours, from 12:00h. to 19:00h.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 kW</td>
<td></td>
</tr>
</tbody>
</table>

Once the definition of the consumption all over the 24 hours of the day, the distribution of this energy use all over the day can be shown as the load factor, see Figure 27.

![Load Factor Distribution](image)

**Figure 27. Load Factor for the Household Level**

From the Figure 27 some conclusions can be made. It is easy to see how the consumption is mainly done during the night where the lighting is used. The peak demand almost reaches the maximum capacity of the supply because the output of the GP is 10 kW, and the peak consumption is 8.6 kW, plus the 1 kW for the telecom tower is 9.6 kW. Another important economical fact related to it is that the load factor for estimated consumption over maximum is 22.99%. That means that close to the 77% of the possible electricity (77% of potential revenues) would be out of use if just household activities were fostered. It is important to point as well that in the studies used as example for this one, the conclusion of this demand distribution was that these household needs were more efficiently covered by battery charging systems.

- **Induced Effects**
  The capacity of people to pay for electricity supply is one of the most interesting facts that can be researched since it is one of the key factors that will influence in
the success of the project. Linking this point to the previous ones, the improvement in social and economical conditions will directly affect the capacity and the will of pay all over the community. In order to assess the willingness to pay of the society, some examples (World Bank Independent Evaluation Group, 2008; The World Blank, 2008) have been used, as the experience of previous works is a priceless resource.

The most basic and efficient analysis to do is the willingness of pay for lighting service, paying electricity for lighting means. It is important because it is probably the most used service among the households. The estimations used for the calculation of the load factor can be applied in this case. On the other hand, the real data for consumption of fuel for lighting can be used in this assessment. Thus, the Table 39 shows the values taken from the section 4.3 Field Trip, 5.2.1 General View of the Application and form the assumptions.

<table>
<thead>
<tr>
<th>Kerosene</th>
<th>Mini-Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td></td>
</tr>
<tr>
<td>10 litres/month</td>
<td>60 W bulb</td>
</tr>
<tr>
<td>0.05 litres/hour(^{10})</td>
<td>5 hours/day</td>
</tr>
<tr>
<td>Usage</td>
<td></td>
</tr>
<tr>
<td>200 hours/month</td>
<td>150 hours/month</td>
</tr>
<tr>
<td>Price</td>
<td></td>
</tr>
<tr>
<td>1.06 USD/litre</td>
<td>0.18 USD/kWh(^{11})</td>
</tr>
<tr>
<td>Lighting(^{12})</td>
<td></td>
</tr>
<tr>
<td>55 lumens</td>
<td>730 lumens</td>
</tr>
<tr>
<td>1.1 kilolumen/month (Q(_k))</td>
<td>109.5 kilolumen/month (Q(_m))</td>
</tr>
<tr>
<td>Investment</td>
<td></td>
</tr>
<tr>
<td>10.6 USD/month (P(_k))</td>
<td>1,62 USD/month (P(_m))</td>
</tr>
</tbody>
</table>

In the Table 39 can be seen that the units used, as lumens/month, have been chosen to facilitate the comparison between the two sources of energy. The selection of lumens is obvious, if lighting is wanted to be assessed there is no better unit that the one that measures the intensity of light (World Bank Independent Evaluation Group, 2008). The investment data shows a significant difference between the two types of lighting, kerosene is 3 times more expensive giving 100 times less light; see Table 39. The chart describing the demand and the willingness to pay for lighting service is shown below; see Figure 28. Although, a few explanations regarding its reliability have to be done previously;

- The demand is lineal because is directly based in the data given in previous sections. A more realistic approach would be achieved from a non-linear demand curve since the lineal one overestimates the surplus that the costumer obtains. Elasticity in demand is not known, is highly dependent on income per household and current economical conditions.
- Electricity supply lowers the cost of energy to the user, resulting in an increase in

\(^{10}\) Source: Rainbow Power Company, 200-
\(^{11}\) Data facilitated by Pamoja Cleantech AB
consumer surplus, which is the difference between what the consumer is willing to pay and what they actually do pay.

To explain which would be the consumer surplus of applying the mini-grid in the community, different areas have been defined in the diagram, see Figure 28. The quantity that the population is currently investing in lighting is “B+D”. “A” defines the extra amount that they could pay. On the other hand, the area defined by “E” is the amount of money the population would have to spend in electricity if they would purchase it from the mini-grid. Then “A+B+C” would be the surplus that the consumer would have between the amount of money they pay for electricity compared to the capacity, or the will of pay.

iii. Conclusion of the estimated economical impacts
The conclusions of the economical impact analysis are not as reliable as desired, the fact that there are many uncertainties involved in this kind of projects reduces the consistency of the results, although, it is clear that those results can be taken as trends or signs of what should happen, despite the exact numbers might not be precise.

The conclusion for each of the effects studies is done below:

- **Total Employment:** To declare a specific number of new jobs or to give concrete data about the improvement of working conditions is impossible at this time. Although it is possible to foresee an increase on community possibilities and opportunities due to the implementation of the GP project.

- **Value Add:** It is possible to see in the previous analysis of this point, the likeliness of increasing the revenues and the household opportunities. Summarizing:
  - Increase of the revenues due to the commercialization of a more developed product: doubling price in the case of coffee.
  - The improvement on life-solutions, conditions and the likely increase on salaries are just few of the possibilities that the community could experience.
- Possible increase on expenditures on the price of energy for agricultural activities. As explained before, it might reduce the capacity of production but the availability of energy and the easy access should counteract the price effect.

- **Induced Effects:**
  - The use of electricity, and so, the consumption could be extremely benefited after the implementation of the mini-grid. The reduction on expenses in electricity could lead to use the money saved in entrepreneurship, greater education, better life-conditions or other issues that are needed by local people.
  - The Increase on the will of pay, thus, increases on expenditures in lighting. As shown in the previous social assessment, the increase in lighting has direct positive effects over the life-conditions of the community.

**B– Battery Charging Station**

a. **Social**

The development of the identification of the potential impacts for the BCS is mainly the same than used before for the mini-grid. In that direction, the first to points of the assessment “ i. Baseline study” and “ii. Identification of the stakeholders” will not be exposed here; for the purpose of the analysis the ones described before for the mini-grid can be used also in this case. Thus, the analysis starts here with the third step of the methodology.

**iii. Identify the major impacts or the most likely possibilities within it.**

The most likely impacts to happen with a direct relation to the BCS implementation are divided in two groups, positive impacts and negative impacts, and described below:

**Positive:**
- **Reduction in consumption of expensive fuel.** The price of diesel is much higher than the energy supplied by the GP. The exact prices and data regarding this point are explained in the following economical analysis.
- The possibility of **reducing the use of kerosene** for house lighting will increase the quality of in-door air and so, have a direct positive impact in people’s health.
- The possibility of empowering the area could contribute with enforcement in community strengthening and stimulating collaboration among the members of it. Especially in between cooperative members.
- **Lighting could as well allow the micro-business to work longer hours** even though when there is no natural light.
- The batteries could **make possible to watch TV** (or listen to radio) for who those could afford a TV. Yet, it would be communal social effect by gathering neighbors, especially children, together and watch TV during the night. This situation would **increase the awareness the current situation of the country and even the world.** In addition, watching the broadcast in English and Luganda (most geographically spread language) could encourage the children learn to speak those languages.
- Battery power for handheld torches, which would be used to travel around the village more easily at night.
The possibility of replacement of dry cell batteries in handheld torches by rechargeable 6V batteries. These included improvements in convenience, finances (villagers no longer needed to buy as many dry cell batteries).

Negative:

- The grid electrification provides AC power and makes it possible to run machinery such as sewing machines, welding irons, milling equipment, etc. On the other hand, the batteries provide DC power and this situation limits the appliances that can run of it. Thus, this application does not allow for a wide range of income generating activities to occur. So, the only income-generating opportunities, which are expected to be created or enhanced, are those that could be performed at night, using lighting run by the batteries. The most common option is expected to be extension of the opening hours of the local village shop.
- To have a battery and become a part of this application might cause an additional cost to the community. The problem with this additional cost might arise not just in the beginning but also during the any time period according the economical condition of the household.

iv. Identify and anticipate the social impacts and possible reactions.

- The limited power capacity of the system compared to the grid electrification. Even though, the lightning and running TV/radio possibilities are very noteworthy changes in the rural areas, the batteries will not help to cope with the main problem, which are the low economical conditions. The batteries should be used may as a common good. Share batteries between some households could help to socialize meanwhile doing the daily tasks.
- Another problem could occur when using the appliances equally among men, women and children of the village. Some of the expected benefits of the lightning are to provide better conditions to women for the domestic work and also to the children for fostering the education. As the lighted area (even the charging station) would be a very social environment, it is important to be sure that is not only shared among men.
- The end-user could get disappointment of the system. To avoid this situation, informing the community about the advantages and drawbacks of the system is important (e.g. informing about the lack of capacity of the batteries). This situation would reduce the disappointment and also remain still the reliability of the project.

b. Environmental Impacts

Step 1 – Project Identification.

The impacts detected are divided into positive and negative.

Positive

- Reduction in the use of diesel, kerosene and firewood. The first two mean a reduction in CO₂ emissions, the latter a reduction to the stress that the woods around the village are subjected to.
- Energy supply origin from a RET source. It means that under sustainability work conditions it should be able to provide energy without problems to future generations.

Negative.
Amongst the negative effects, there are the leakages of the toxic chemicals that compound the batteries.

- **The most common intake of lead for man is the inhalation of lead dust and ingestion of contaminated water, soil and food.** The dangerous part is that it is difficult to diagnose the intake, because the lead contamination causes very general symptoms. **One early effect of high levels of lead contamination in the blood is anemia, of which the early symptoms are fatigue, headache and lassitude.** Prolonged lead exposure may produce effects on the Central Nervous System, with symptoms like physiological and behavioral changes. This effect is much more important to children (World Health Organization, 2011).

- **The lead particles can reach drinking water supplies by soil since the lead can easily transport in an acidic environment.** In addition, this poured out lead can be easily contaminated into the agricultural fields.

- The electrolyte is made up of sulphuric acid, which can make its way through clothes and skin, and has an adverse affect on the environment. In addition the electrolyte in an old battery is highly contaminated with lead particles.

- **An overcharged battery has the risk of explosion.** The overcharging may lead the gas escape from the battery and cause an explosion.

**Step 2 – Pre-feasibility study.**
The environmental problems with the BCS are not only viable for this application but for every single use of the lead-acid batteries. However, it is possible to prolong the lifetime and improve the efficiency of the battery by performing some very simple maintenance activities and practical considerations. In addition, informing and training the society about the use of battery and sustainability issues would give positive output for this specific application and also for the ultimate purpose of achieving sustainable development.

**Step 3 – Project design.**

i. The more likely negative impacts to happen under the current design of the application are caused by the chemicals and the design of the battery, those are:

   - The lead contamination to the environment. Negative impacts to the nature and to the human health.
   - Misuse and false disposal of the battery.

ii. There are different advises that should be followed to avoid having environmental-related problems during the functioning of the BCS application.
The amount of acid in the electrolyte should remain constant and the amount of the water and charge status forms the acid concentration which is 1.20-1.28 \( \text{g/cm}^3 \) for a fully charged battery ranges from, depending on type and brand (Lorenzo, 1994). Due to evaporation and gassing there is always some loss of water from the electrolyte. If the loss is severe, the plates are exposed to air and will oxidize and cause breakdown. By checking the water level in every 2-3 months, the electrolyte level could be held above the plates. Then, the water should be added if it is needed.

The charge controller is designed to protect the battery and keep the lifetime longer. The operating of the charger does not require a specific knowledge but does require consistent care.

The stakeholders should take into account the gravity of the aspect and pay attention on disposal and recycling systems. The lead is a recyclable and most of the battery manufacturers collect the scrap batteries to recycle.

c. **Economical Impacts**

   i. **Definition of the area under the influence of the project.**

   Here again, the influenced area is the entire village of Sekanyoni. Nevertheless, the application is basically open for everyone. The company could also get numerous customers from the neighbor villages. The end-users who are already using charging station could choose coming here to charge their batteries since the pilot site would be nearby and the tariff is expected to be less. This would reduce the end-user expenses on the battery charging.

   ii. **Identification and analysis of the direct effects**

   - **Total Employment**

     As it has been discussed before, the business prediction is least expected to create new business opportunities for the community. However, it is expected to distinguish a positive business generation for the grocery shops. On the other hand, this application has a bigger business potential for the neighbor villages, including the grocery shop effect, mobile charging services, and dry cell battery services. Even in a bigger scope, some entrepreneurs could start to charge batteries at the GP station and rent them in their villages. Thus, it is still likely to achieve a positive economical impact and foster micro-finance business.

   - **Value Add**

     As it is in the mini-grid application, (although it is expected to be in smaller proportion) it is certain that the income level per household would be increased. On the other hand, BCS does not aim to add a new value to a certain product, which the community currently produces.
iv. **Conclusion of the estimated economical impacts for each scope of work.**
In the conclusion, the significant economical aspects of the application is not coming from either value adding or creating new business opportunities but it is coming from decreasing the expenses of the community, such as:
- Cheaper battery charging (the current charging fee per battery is 1500-2000 UGX)
- Cheaper cell-phone charging
- Cutting off the transportation costs of the battery charging purposes
- If there is a new beauty salon, cutting off the transportation costs of going to another village/town
- Increased trade in the shops

C. Heat Pipe Exchanger
   a. Social
The development of the identification of the potential impacts for the BCS is mainly the same than used before for the mini-grid. In that direction, the first two points of the assessment “i. Baseline study” and “ii. Identification of the stakeholders” will not be exposed here; for the purpose of the analysis the ones described before for the mini-grid can be used also in this case. Thus, the analysis starts here with the third step of the methodology.

iii. **Identify the major impacts or the most likely possibilities within it.**

Positive
- **Positive impact on the agricultural activities.** Application of the technology on the agricultural production. Production with more professional and modern methods.
- **Forecasting** opportunities for the production time and maintaining better relationship with the customer in terms of delivery time and amount.
- Alleviate poverty through **increase on the production activities**, employment generation and wage increase.
- Increasing of the motivation and self-confidence of the agriculture cooperative to take an action in similar projects.
- Increasing of the willingness of becoming of a cooperative member.
- Increasing of the interest of the other organizations to take an action in the same area.

Negative
- **Possible conflicts on the scheduling of using the heat exchanger.**
- In case of being unsuccessful, **the interest of the community could decrease** (for this project and for the similar environmental studies).
- Time required learning how to use the heat exchanger.

iv. **Identify and anticipate the social impact and possible reactions.**
The field trips have showed that the communities are usually open to any kind of new application. Especially, the willingness of using technology is fairly high. Hence, the
foreseeing use of the application is that the coffee producers would like to try and be part of the application. Presumably, the first upcoming benefits of the application would be improving on the time and efficiency of the drying process. However, the biggest difference which would the application make is that to provide more predictable production timing to the farmers. The improved relationship between supplier and the wholesaler would likely to increase the business activities between two sides. For instance, scheduled deliveries are always more attractive for the wholesalers, thus, there is a possibility for the cooperative to make a difference among the other farmers and increase their annual sales.

b. Environmental Impacts

Step 1 – Project Identification.
Positive
- An application of waste energy recovery.
- Increased energy efficiency and conservation.
- The recovered energy is equal to 20% of the heat power that is accumulated inside the container, according to the data from GEK gasifier regarding heat loss of the system.

Negative
- Electricity consumption of the device.
- Negative environmental impacts out of the used material of the device if the disposal phase is not performed correctly.

Step 2 – Pre-feasibility study
In order to perform the drying process by the heat exchanger efficiently, it is important to train the users and supervise the process. It would prevent to misuse and the possible negative impact of the application. It would be helpful to work together with the stakeholders and control the process in the beginning.

Step 3 – Project design
In this case, the environmental impacts are not highly dependent on the design of the project. The impacts are more related to usage phase of the heat exchanger and maintaining it. This application requires the adjustment of a new device to a community, which is not using any additional machinery for this process. Accordingly, this situation brings the negative impacts such as electricity consumption and additional machinery to the environment.

c. Economical Impacts

i. Definition of the area under the influence of the project.
The application area is going to be the pilot village and the main target and partner of the application are going to be Magara Farmers Cooperative (productive and agricultural activities). However the end-users who would like to apply this new drying process
method could benefit from outside the village and farmer cooperative.

**ii. Identification and analysis of the direct effects**

- **Total Employment**
The application is not expected to create new business opportunities at the first side. But it is possible to cause a positive impact on agricultural activities. So, by time, the number of farmers or employment could increase and the importance of the agricultural process could ascend in terms of economical benefits.

- **Value Add**
The added value is not coming from improved quality of the coffee product or it is not related to providing another function or so. Nevertheless, the additional value is coming from the faster production phase. In other words, the application adds a new value to the producer not to the product. Increased value of the cooperative and the farmers is expected to attract more customers and provide more trade. Besides, the improved drying process would eliminate the long processing time and avoid the undervalue sales. Also it would allow trading the goods with money in a shorter time.

**iii. Conclusion of the estimated economical impacts for each scope of work**

It is a difficult task to calculate the exact outcomes of the application in monetary values. Nevermore, it is possible to observe the possible economical impacts by looking at the coffee market conditions and process in Uganda.

- According to the Uganda Coffee Development Authority (UCDA), the coffee production sector is almost completely dependent on the small-scale farmers and it is stated that the large-scale centralized coffee production is needed for the industry. Even though this picture looks like a drawback, it is also stated that the situation helps to cope with the uncertainties of the world market prices, since; the small-scale producers have low marginal costs of production.

- One of the most significant costs of the production phase is the drying issue. The selling price of the coffee is directly dependent on the moisture content of the coffee beans. The fully dried coffee beans could be sold to the value of the good. Conversely, the high moisture content causes falling in value. The expected moisture content of the dried coffee is 13-14 % and it usually takes 2 weeks. As the moisture content goes high, the price of the coffee goes down. Besides, it is pointed out that the delayed drying could result on the quality of the product and decrease the value.

- In addition, Oxfam (Oxford Community for Famine Relief) has made some case studies on the importance of coffee production in Uganda (Sayer, G., 2002). In the research, it is mentioned that drying process is up to the economical conditions of the farmers. It means that, sometimes the farmers are forced to sell their goods before they are dried enough for the market requirements. Especially, this occurs if there is sickness in the family or an urgent need of sugar, salt or any basic food product. Uncompleted dried coffees (sometimes they sell right after starting drying process) are sold to the small traders, which continue to the drying process and sell the coffee with higher prices. According to the report (Sayer, G., 2002), the farmers
sometimes sell up to 1000 kg non-dried coffee in one year with a price down to 0.20 USD/kg (average price of the dried coffee is 0.79 USD/kg).

5.2.1 SWOT Analysis

The SWOT methodology is a framework used in the analysis of a project in order to create a strategic planning to it, thus spotting the strengths, weaknesses, opportunities and threats (as SWOT is the acronym of these four points) (Hill & Westbrook, 1997). A good description of SWOT is stated by Stacey, (1993 cited in Pickton & Wright, 1998, p. 103); he defines SWOT as:

“A list which shows the strengths and weaknesses of an organization by an analysis of its resources and capabilities; and a list of the threats and opportunities which is identified by analyzing its environment. Strategic logic obviously requires that the future pattern of actions to be taken should match strengths with opportunities, ward off threats, and seek to overcome weaknesses.”

The reasons, that brought the authors of this research to think that SWOT is a procedure that fits the needs of the study, are based on the fact that this approach takes in account the internal and external factors of the project. In order to understand that statement, the internalities and externalities are going to be defined following the differentiation made by Karppi, et al. (2001); in the paper, describes that the main distinction between the internal and external factors is the degree of control over them. The internal ones are characterized by their direct relation with the project itself, and should be controllable by the managers or directors of it. On the other hand, the external factors are influenced by the environment and its changes, not just referring to the natural environment but the economical and socio-cultural movements and flows.

The first step that must be done during the development of a SWOT analysis has to be, always, an overview of the project and its surrounding; the study of the environment, socio-cultural aspects, and all these factors that are or could affect the successful development of the project, as it can be found out in Pickton &Wright (1998) examples.

In this sense, the data collected and the analysis were done during the research trip to Uganda, more specifically to the placement where the pilot plant is to be constructed. The collaboration of other members of the company, (Pamoja Cleantech AB) as well as the interviews with the locals, helped in order to obtain reliable and useful information. Moreover, the conclusions of the previously performed analysis (5.2 Potential Impact Identification) are the statements that will be used to complete the SWOT analysis.

Once the research of relevant information is done, the next step is to frame all these data in a matrix format, as it can be seen as example the following chart, see Figure 32 (Markovska, et al. 2009, p.755):
Pickton & Wright (1998) consider that leaving the analysis at point is a mistake, they declare that a more profound analysis is necessary to have a reliable and discussed order of factors. Kotler (1991, cited in Pickton & Wright, 1998, p.106) proposes that, as an improvement of the conventional SWOT method, another matrix should be done. This second matrix must be focused on the external factors (threat and opportunity) classifying hierarchically the statements in two different scopes, by degree of impact and probability of occurrence. In the same direction, it is suggested that the internal factors could be disposed by order of importance. After ordering all the factors within the new criteria, the elements that are more significant and likely to happen are highlighted so it is easier to focus on them.

In this case, the SWOT has to contribute to the understanding of the impacts related to the implementation of the product developed in this study. This methodology is used in order to classify the different outcomes of the two previous analysis (section 5.2 Potential Impact Identification), so it is clear which of them can be managed (internal) or just treated carefully (external). The SWOT output is useful for the final design of the selected applications, so is done in order to give a solution to the research question and sub-questions. In this direction, the SWOT analysis performed in this research would include the second improvement chart (Kotler, 1991, cited in Pickton & Wright, 1998, p.106), so the researchers reach a deeper and more realistic view, and have more tools for a richer discussion. Therefore, taking in account these results provide an efficient and sustainable final design of the whole system.

### A- Mini-Grid

The SWOT analysis is used in this research as a final conclusion of the assessment. It states the main facts of the project discussed and defended in the previous stages of the development of the results and, as it is one of SWOT’s purposes, clustering them
depending on their origin and nature. In the Table 40, the mentioned impacts and analysis are included.

Table 40. SWOT Analysis for the Mini-Grid

<table>
<thead>
<tr>
<th>Positive</th>
<th>Strengths</th>
<th>Negative</th>
<th>Weaknesses</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>• Good predisposition of local people to use the electricity.</td>
<td></td>
<td>• Existence of very few enterprises in the area.</td>
<td>• Possible supply failure.</td>
</tr>
<tr>
<td></td>
<td>• Energy price and market competitiveness.</td>
<td></td>
<td>• Small energy capacity.</td>
<td>• Lack of reliability on the improvement of economical activities over population.</td>
</tr>
<tr>
<td></td>
<td>• No business competitors.</td>
<td></td>
<td>• High dependence on cooperative for revenues.</td>
<td>• Possible creation of a need related to energy supply.</td>
</tr>
<tr>
<td></td>
<td>• Community already organized as a cooperative.</td>
<td></td>
<td>• Lack of experience regarding the business model.</td>
<td>• Positive impacts must be correctly managed to avoid a social break up between poor and rich people.</td>
</tr>
<tr>
<td></td>
<td>• Health benefits because of fossil fuel substitution.</td>
<td></td>
<td>• No constant demand.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Possibility of covering almost all daily-life needs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Educational improvements.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reduction of time spent for daily-tasks, which means increase on leisure time.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increase on comfort.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Possibility of working, studying or doing other activities after the sunset.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td>• Entrepreneurship potential.</td>
<td></td>
<td>• Possible institutional customers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Micro-financing possibilities.</td>
<td></td>
<td>• Likely increase in job opportunities and wages.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increase on cooperative revenues.</td>
<td></td>
<td>• Enforcement in social activities, gathering to spend leisure time together, read or study.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Traditional fuel rising price.</td>
<td></td>
<td>• Increase on other economical activities and migration due to energy disposition.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Possible institutional customers.</td>
<td></td>
<td>• Increase on productivity and storage possibility empowers the food sovereignty.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Likely increase in job opportunities and wages.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increase on cooperative revenues.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Once the matrix is completed, see Table 40, the second matrix must be done in order to arrange the statements hierarchically on relevance, see Table 41. This second matrix is planned to focus on the external factors (threat and opportunity) classifying the statements in two different scopes, by degree of impact and probability of occurrence. In the same direction, it is suggested that the internal factors could be disposed by order of importance. The mentioned data is included and arranged in Table 41.
Table 41. Improved SWOT matrix for the Mini-Grid

<table>
<thead>
<tr>
<th>Positive</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Community already organized as a cooperative.</td>
<td>1. Increase on cooperative revenues.</td>
</tr>
<tr>
<td>2. Good predisposition of local people to use the electricity.</td>
<td>2. Increase on productivity and storage possibility empowers the food sovereignty.</td>
</tr>
<tr>
<td>4. Health benefits because of fossil fuel substitution.</td>
<td>4. Likely increase in job opportunities and wages.</td>
</tr>
<tr>
<td>5. Educational improvements.</td>
<td>5. Entrepreneurship potential.</td>
</tr>
<tr>
<td>7. Possibility of covering almost all daily-life needs.</td>
<td>7. Increase on other economical activities and migration due to energy disposition.</td>
</tr>
<tr>
<td>8. Reduction of time spent for daily-tasks, which means increase on leisure time.</td>
<td>8. Enforcement in social activities, gathering to spend leisure time together, read or study.</td>
</tr>
<tr>
<td>10. Possibility of working, studying or doing other activities after the sunset.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Existence of very few enterprises in the area.</td>
<td>1. Possible supply failure.</td>
</tr>
<tr>
<td>2. High dependence on cooperative for revenues.</td>
<td>2. Possible creation of a need related to energy supply.</td>
</tr>
<tr>
<td>3. Small energy capacity.</td>
<td>3. Lack of reliability on the improvement of economical activities over population.</td>
</tr>
<tr>
<td>4. No constant demand.</td>
<td>4. Positive impacts must be correctly managed to avoid a social break up between poor and rich people.</td>
</tr>
</tbody>
</table>

Finally, after ordering all the factors within the new criteria, the elements that are more significant and likely to happen are highlighted so it is easier to focus on them.

B- Battery Charging System

Table 42. SWOT Analysis for the BCS

<table>
<thead>
<tr>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-----</td>
</tr>
<tr>
<td><strong>Strengths</strong></td>
<td></td>
</tr>
<tr>
<td>• Good predisposition of local people to use the electricity.</td>
<td></td>
</tr>
<tr>
<td>• Energy price and market competitiveness.</td>
<td></td>
</tr>
<tr>
<td>• There are business competitors but far away and more expensive</td>
<td></td>
</tr>
<tr>
<td>• Community already organized as a cooperative.</td>
<td></td>
</tr>
<tr>
<td>• Health benefits because of fossil fuel substitution.</td>
<td></td>
</tr>
<tr>
<td>• Possibility of covering daily-life needs.</td>
<td></td>
</tr>
<tr>
<td>• Educational improvements.</td>
<td></td>
</tr>
<tr>
<td>• Reduction of time spent for daily-tasks, which means increase on leisure time.</td>
<td></td>
</tr>
<tr>
<td>• Increase on comfort.</td>
<td></td>
</tr>
<tr>
<td>• Possibility of working, studying or doing other activities after the sunset.</td>
<td></td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td></td>
</tr>
<tr>
<td>• Existence of very few enterprises in the area.</td>
<td></td>
</tr>
<tr>
<td>• Very limited energy capacity.</td>
<td></td>
</tr>
<tr>
<td>• High dependence on cooperative for revenues.</td>
<td></td>
</tr>
<tr>
<td>• Lack of experience regarding the business model.</td>
<td></td>
</tr>
<tr>
<td>• No constant demand.</td>
<td></td>
</tr>
<tr>
<td>• Possibility of lack of interest according to limited business opportunities</td>
<td></td>
</tr>
<tr>
<td><strong>Opportunities</strong></td>
<td></td>
</tr>
<tr>
<td>• Entrepreneurship potential.</td>
<td></td>
</tr>
<tr>
<td>• Traditional fuel rising price.</td>
<td></td>
</tr>
<tr>
<td>• Possible institutional customers.</td>
<td></td>
</tr>
<tr>
<td>• Enforcement in social activities, gathering to spend leisure time together, read or study.</td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>External</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
</tr>
</tbody>
</table>
| **Positive** | 1. Community already organized as a cooperative.  
2. Good predisposition of local people to use the electricity.  
3. Energy price and market competitiveness.  
4. Health benefits because of fossil fuel substitution.  
5. Educational improvements.  
6. Business competitors but far away and more expensive.  
7. Possibility of covering daily-life needs.  
8. Reduction of time spent for daily-tasks, which means increase on leisure time.  
9. Increase on comfort.  
10. Possibility of working, studying or doing other activities after the sunset. | 1. Enforcement in social activities, gathering to spend leisure time together, read or study.  
2. Entrepreneurship potential.  
3. Traditional fuel rising price.  
4. Possible institutional customers. |
| **Negative** | 1. Very limited energy capacity.  
2. Existence of very few enterprises in the area.  
3. Possibility of lack of interest according to limited business opportunities.  
4. High dependence on cooperative for revenues.  
5. No constant demand. | 1. Lack of reliability on the improvement of economical activities over population.  
2. Possible supply failure. |

C– Heat Pipe Exchanger
### Table 44. SWOT Analysis for the Heat Pipe Exchanger

<table>
<thead>
<tr>
<th>Positive</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
</table>
| Strengths | • No business competitors  
• Community already organized as a cooperative  
• Possibility of increasing coffee production activities  
• Eliminating of the drawbacks of the unpredictable drying process  
• Eliminating the long processing time | Opportunities | • Entrepreneurship potential. |

<table>
<thead>
<tr>
<th>Negative</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
</table>
| Weaknesses | • Dependent on cooperative interest  
• Lack of experience  
• Possibility of lack of interest according to uncertainties | Threats | • Possible supply failure |

| Table 45. Improved SWOT Matrix for the Heat Pipe Exchanger |

<table>
<thead>
<tr>
<th>Positive</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
</table>
| 1. Eliminating the long processing time  
2. Eliminating of the drawbacks of the unpredictable drying process  
3. No business competitors  
4. Possibility of increasing coffee production activities  
5. Community already organized as a cooperative | | 10. Entrepreneurship potential |

<table>
<thead>
<tr>
<th>Negative</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
</table>
| 1. Possibility of lack of interest according to uncertainties  
2. Lack of experience regarding the business model  
3. Dependent on cooperative interest | | 5. Possible supply failure. |
5.3 Final View of the Product

The final section of this report consists of two main parts, the budget and the comparison of the designed system with the current situation in the pilot site in terms of energy consumptions and expenses. The authors would like to conclude this report by emphasizing an actual vision of what is done throughout the research; show the outcome of the ultimate objective of the work, expose the comparison based on the collected data, and the estimations done based on the literature review, where the studied applications will be applied.

5.3.1 Budget

In order to estimate the final budget of the project, a spreadsheet has been used. The Figure 30 is based on all the components that are involved in the developing of the products and the entire system. The table consists of the prices of the each component and transportation costs which are explained in the product design overview. The design conditions followed are the ones given in the section 5.2 Potential Impact of the Selected Solutions, under each product sub-title. Thus, the budget is entirely defined in the Figure 30.

<table>
<thead>
<tr>
<th>Application</th>
<th>Part</th>
<th>Item</th>
<th>Cost / Unit (USD)</th>
<th>Unit</th>
<th>Total (USD)</th>
<th>Cost System (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini-grid</td>
<td>Conductor</td>
<td>Material</td>
<td>-</td>
<td></td>
<td>15.699,84</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport</td>
<td>-</td>
<td></td>
<td>4.725,76</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labour</td>
<td>-</td>
<td></td>
<td>3.203,20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Productive Use</td>
<td>Inverter</td>
<td>1</td>
<td></td>
<td>2.600,00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Battery Charging</td>
<td>Battery</td>
<td>6</td>
<td></td>
<td>4.470,00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others</td>
<td>-</td>
<td></td>
<td>2.630,00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electric Motor</td>
<td>Engine</td>
<td>1</td>
<td></td>
<td>1.874,00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Milk Tank</td>
<td>Tank</td>
<td>1</td>
<td></td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>35.202,80</td>
<td><strong>35.202,80</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Battery Charging</strong></td>
<td>Battery Charger</td>
<td>340</td>
<td>1</td>
<td>340,00</td>
<td>3.340,00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery</td>
<td>100</td>
<td>30</td>
<td>3.000,00</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Heat Pipe Exchanger</strong></td>
<td>Heat Exchanger</td>
<td>CC2000 Model</td>
<td>2820</td>
<td>2</td>
<td>5.640,00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat Pipes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>44.182.80</strong></td>
<td><strong>44.182.80</strong></td>
</tr>
</tbody>
</table>

*Figure 30. Budget of the Selected Applications*

5.3.2 Final Layout of the System

The very final stage of the thesis is to evaluate the functioning of all the applications within the system. The researchers have finalized the report with the most likely future scenario is one where all these applications, and even others that have not been assessed in this work, are working together, providing different services to a community economically advancing and with a growing potential demand. The success of the first
energetic improvements will lead to an escalating will to have those resources at community disposal.

This last step, to conclude the research, is to set out a possible future scenario likely to happen in the village under study. The results obtained during the research are going to be used in this part, and those are the fundamental basis, the whole work developed is used as an example of how the output of the thesis could work. Thus, in order to start with the last stage of the report, the first step is to raise the characteristics of the scenario.

First of all, the authors have used the current energy consumption data, which is collected during the site visits and shown in the field trips section of this report; in order to obtain the energy demand in electricity energy unit (kWh). There is an important statement to be done is that the scenario is based on the harvesting season. This is decided in order to enrich the analysis a scenario based on the harvest season means a productive uses at its maximum.

The development of this analysis is divided in three parts: Demand Analysis, Configuration of the System and Energy Expenses. Each of these parts has been also divided according to the user lever as: productive use, community services and household usage.

1. Demand Analysis

   a. Productive Use

   The productive uses, as have been defined in previous parts of the work, are the activities regarding the cooperative and the industrial activities. The processes on going in the industrial area are the ones with a greater demand. The two main activities carried out in the productive area are milling and seed-drying. The milling involves the use of lighting; the Table 46 shows how these activities are defined.

   \begin{table}[h]
   \centering
   \begin{tabular}{|l|c|c|}
   \hline
   Activity & Peak load (kW) & Duration \\
   \hline
   Milling & 9.54 & 2 months/season \\
   Drying & 2.2 & 3 weeks/season \\
   Lighting & 0.12 & During milling \\
   \hline
   \end{tabular}
   \caption{Peak Load for the Productive Use Activities}
   \end{table}

   The peak coincident load for the productive activity will be reached when the drying and milling processes are overlapped, this is happening one week per season, and its peak load is 11.85 kW. The demand for each of the harvesting weeks is shown in Figure 31.
As it can be seen in Figure 31, the demand during the week when the milling and the drying is performed simultaneously, reaches 11.85 kW. Knowing the peak load for the mini-grid is 9 kW and for the batteries is 2.2 kW, it is easy to see that the 11.2 kW that could be provided by those two systems cannot cover the demand. Thus, the agricultural activities are to be done separately.

b. Community Services
The activities accounted as community service are the two schools and the two stores placed in the village area. The characteristics of this customer are shown in the Table 47.

Table 47. Community Services, Customer Characteristics

<table>
<thead>
<tr>
<th>Activity</th>
<th>Peak load/unit (kW)</th>
<th>Working Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store</td>
<td>0.78</td>
<td>10:00h. to 18:00h.</td>
</tr>
<tr>
<td>School</td>
<td>0.7</td>
<td>9:00h. to 16:00h.</td>
</tr>
</tbody>
</table>

The trade center holds and extra-activity serving as a battery charging station, having the capacity of 5 batteries simultaneously.

The total consumption of the four community amenities can be seen in Table 48.

Table 48. Consumption of the Community Services

<table>
<thead>
<tr>
<th>Activity</th>
<th>Peak load/unit(kW)</th>
<th>hours/day</th>
<th>Consumption kWh/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store</td>
<td>0.78</td>
<td>8</td>
<td>6.24</td>
</tr>
<tr>
<td>School</td>
<td>0.7</td>
<td>7</td>
<td>4.9</td>
</tr>
<tr>
<td>Total</td>
<td>2.96</td>
<td></td>
<td>22.28</td>
</tr>
</tbody>
</table>
c. Households
The main activities related to the electricity consumption in the households are lighting, the energy use linked to the leisure time, like radio listening, and phone charging. Regarding the “other” uses, they make reference to the activities that use electricity such as hairdressing, use of kettles or any other possible utility. These are described next; see Table 49.

Table 49. Use of Energy in the Household Level

<table>
<thead>
<tr>
<th>Activity</th>
<th>Peak load/unit (kW)</th>
<th>Time-spent per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>0.06</td>
<td>18:00h. - 23:00h.</td>
</tr>
<tr>
<td>Radio</td>
<td>0.005</td>
<td>20:00h. – 00:00h.</td>
</tr>
<tr>
<td>Phone-charger</td>
<td>0.005</td>
<td>15:00h. – 17:00h. / 21:00h. – 22:00h.</td>
</tr>
<tr>
<td>Others</td>
<td>0.01</td>
<td>20:00h. – 21:00h.</td>
</tr>
</tbody>
</table>

The total consumption, of one single household, of energy per day is shown below, in Table 50.

Table 50, Total Energy Consumption in the Household Level

<table>
<thead>
<tr>
<th>Activity</th>
<th>Peak load (kW)</th>
<th>Hours/day</th>
<th>Consumption kWh/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>0.06</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Radio</td>
<td>0.005</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>Phone-charger</td>
<td>0.005</td>
<td>1</td>
<td>0.005</td>
</tr>
<tr>
<td>Others</td>
<td>0.01</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>0.08</td>
<td></td>
<td>0.335</td>
</tr>
</tbody>
</table>

In this stage, the efficiency of the system is checked out, there are different configurations assessed in order to see if the energy produced is used, and so, increase the effectiveness of the whole system.

2. Configuration of the System

The next calculations and figures show the different load factors assessed for the different customers and evaluation the maximum coincident load reachable under safe conditions. In that direction, the first load factor assessed is including the demand of the households and the community services, those within the time and load defined previously; see Figure 32.
The amount of energy used over the total potential supply (9 kWh) is only of the 20.13%. It means a really low load factor.

Out of the distribution of this demand it is easy to see that during the night hours the demand is null. So, this can be used to charge the battery system if needed and in that way obtaining a net profit. Assuming that the trade centre has 5 batteries, and using the data given previously, in the Table 51 the data regarding the batteries can be found; in the Figure 33 the new load distribution is shown.

Table 51. Support Battery Charging Characteristics

<table>
<thead>
<tr>
<th>Device</th>
<th>Storage Capacity (kW)</th>
<th>Inverter Capacity (kWh)</th>
<th>Charging time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini-grid Battery System</td>
<td>6.72</td>
<td>2.2</td>
<td>3.05 hours</td>
</tr>
<tr>
<td>Battery Charging St.</td>
<td>4.9</td>
<td>--</td>
<td>7 hours</td>
</tr>
</tbody>
</table>
The battery charging stations start working at 00:00h am, around 3:30h am the mini-grid battery system is fully charged, and by the time the schools start using the energy, the trade centre charging station is complete. For this configuration, the new load factor is 24.86%, slightly better.

The next step is to add the productive uses, the agricultural means. First, just the drying is evaluated. As proved before, both agricultural activities cannot be held at the same time, and thus must be analyzed separately. The Figure 34 shows the new load distribution.
The load factor under these conditions is 33.60% of the total capacity, and although it is improving, the configuration with the milling system, which is the one that has the biggest load, is assessed below; see Figure 35. The mill needs to work taking the energy from the batteries and the mini-grid at the same time. It is a bit complicated, and the work is subjected to the duration of the batteries. In the Table 52 there is defined the series of hours that the mill can work, that is done in order to know how long will the batteries last under the load regime. Obviously, as is the coincident load factor the one evaluated, the mill is active simultaneously to the households and community service.

Table 52. Milling and Battery Supply Performance, Working Hours Under Peak Load

<table>
<thead>
<tr>
<th></th>
<th>Working Hours</th>
<th>8 - 9</th>
<th>9 - 10</th>
<th>10 - 11</th>
<th>11 - 12</th>
<th>12-13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Community (kW)</td>
<td>0</td>
<td>1.4</td>
<td>1.54</td>
<td>1.14</td>
<td>2.96</td>
</tr>
<tr>
<td></td>
<td>Milling &amp; Light (kW)</td>
<td>9.66</td>
<td>9.66</td>
<td>9.66</td>
<td>9.66</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>0</td>
<td>11.06</td>
<td>11.2</td>
<td>10.8</td>
<td>2.96</td>
</tr>
<tr>
<td>Supply Load</td>
<td>Mini-grid</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Battery back-up</td>
<td>0.66</td>
<td>2.06</td>
<td>2.2</td>
<td>1.8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Battery Load Left</td>
<td>6.72</td>
<td>6.06</td>
<td>4</td>
<td>1.8</td>
<td>0</td>
</tr>
</tbody>
</table>

It is clear that the mill can work as long as there is power to run it. The battery and the mini-grid can together supply the mill motor for 4 hours, from 8:00 am. to 12:00 am. When the capacity of the battery is diminishing at cannot supply the whole load of the community and the mill, the mill will have priority having like this, the amount of electricity needed to cover the need of the electrical motor. In the Figure 35 it can be seen how the incorporation of this affects the distribution of the load.

Figure 35. Load Distribution of the Milling, Community Service, Households and Battery Charging Stations

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The load factor in this case is up to 41.84% of the total capacity. It is the higher, and so, this configuration is the most efficient, all the equipment working along the day in separated hours.

3. Energy Expenses

a. Productive Use
According to the data collected during the field trip, for productive uses the total coincident load for the harvesting season would be as described in Table 53.

Table 53. Consumption of Energy Under the Working Condition Restricted by the Energy Supply

<table>
<thead>
<tr>
<th>Activity</th>
<th>Peak load (kW)</th>
<th>Time</th>
<th>Days/season</th>
<th>Consumption (kWh/season)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling</td>
<td>9.54</td>
<td>4 hours/day</td>
<td>120</td>
<td>4579.2</td>
</tr>
<tr>
<td>Lighting</td>
<td>0.12</td>
<td>4 hours/day</td>
<td>120</td>
<td>57.6</td>
</tr>
<tr>
<td>Drying</td>
<td>2.19</td>
<td>5 hours/day</td>
<td>21</td>
<td>45.99</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td><strong>4682.79</strong></td>
</tr>
</tbody>
</table>

The current fuel consumption compared with the electricity conditions offered by Pamoja, which aims to sell the kWh at 0.18 USD, are shown below, see Table 54.

Table 54. Energy Cost, Diesel Compared to Electricity

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Consumption</th>
<th>Cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>70 litres/week</td>
<td>600 litres/season</td>
<td>1.06 USD/litre</td>
</tr>
<tr>
<td>Electricity</td>
<td>4682.79 kWh/season</td>
<td>0.18 USD/kWh</td>
<td>842.90 USD/season</td>
</tr>
<tr>
<td>Diesel Cost</td>
<td></td>
<td>636 USD/season</td>
<td></td>
</tr>
<tr>
<td>Cost difference</td>
<td></td>
<td><strong>206.90 USD/season</strong></td>
<td></td>
</tr>
</tbody>
</table>

The Table 54 shows that the price of the diesel is 25% cheaper than the electricity, looking at this figures, it is obvious that the cooperative members would choose to use diesel. The price of the kWh must be reduced in order to be competitive with the current energy source. A price of 0.136 USD would reduce the cost of electricity to 636.86 USD, matching the current investment in diesel. The Table 55 shows how the pricing would be.

Table 55. Annual Cost of Mini-grid Electricity for Productive Uses

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Consumption</th>
<th>Cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>4682.79 kWh/season</td>
<td>0.136 USD/kWh</td>
<td><strong>636.86 USD/season</strong></td>
</tr>
</tbody>
</table>

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The battery charging system that backs up the mini-grid supply has a constant consumption throughout the year, which can be seen in the Table 56.

**Table 56, Mini-grid Battery Charging System, Annual Consumption and Expenses**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption (kWh/day)</th>
<th>Cost (kWh)</th>
<th>Annual Consumption (kWh)</th>
<th>Annual Expenses (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini-grid Battery Charg.</td>
<td>6.72</td>
<td>0.18</td>
<td>2452.8</td>
<td>441.50</td>
</tr>
</tbody>
</table>

The definition of the price for each service depends on the success of its implementation and the satisfaction of the community. The value added to the product by the improvements in agricultural machinery should allow a higher tariff in the future, and so an increase in the total revenues, meaning a reduction in the global pay-back time of the system.

b. Community Services
The total energy consumption due to social activities is defined in the Table 57. This load includes the battery charging station as well placed in each of the stores. The total annual expenses correspond to the amount of energy used for business as well as school purposes.

**Table 57, Total Consumption for the Community Services**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption (kWh/day)</th>
<th>Cost (kWh)</th>
<th>Annual Consumption (kWh)</th>
<th>Annual Expenses (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store (2)</td>
<td>12.48</td>
<td>0.18</td>
<td>4555.2</td>
<td>819.94</td>
</tr>
<tr>
<td>School (2)</td>
<td>9.8</td>
<td>0.18</td>
<td>3577</td>
<td>643.86</td>
</tr>
<tr>
<td>Total</td>
<td>22.28</td>
<td></td>
<td>8132.2</td>
<td>1463.80</td>
</tr>
</tbody>
</table>

c. Households
The consumption at the household level includes all the services mentioned before. In the Table 58, it is possible to see that at a household level the reduction of the annual cost would be of the 85%. Furthermore, the efficiency of the light would be much higher as the kerosene provides 92.5% less kilolumens than a light bulb.

**Table 58, Comparison Between Kerosene and the Mini-Grid Consumption at Household Level**

<table>
<thead>
<tr>
<th></th>
<th>Kerosene</th>
<th>Mini-Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td>10 litres/month</td>
<td>60 W bulb</td>
</tr>
<tr>
<td>Usage</td>
<td>200 hours/month</td>
<td>150 hours/month</td>
</tr>
<tr>
<td>Price</td>
<td>1.06 USD/litre</td>
<td>0.18 USD/kWh(^{13})</td>
</tr>
</tbody>
</table>

\(^{13}\) Data facilitated by Pamoja Cleantech AB
In the Table 59 it is shown a detailed description of the different life solutions provided by the use of electricity for one household and the annual expenses related to it.

<table>
<thead>
<tr>
<th>Activity / household</th>
<th>Consumption (kWh/day)</th>
<th>Cost (kWh)</th>
<th>Annual Consumption (kWh)</th>
<th>Annual Expenses (USD) / household</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>0.3</td>
<td>0.18</td>
<td>109.5</td>
<td>19.71</td>
</tr>
<tr>
<td>Phone Charg.</td>
<td>0.005</td>
<td>0.18</td>
<td>1.825</td>
<td>0.3285</td>
</tr>
<tr>
<td>Radio</td>
<td>0.02</td>
<td>0.18</td>
<td>7.3</td>
<td>1.314</td>
</tr>
<tr>
<td>Other</td>
<td>0.1</td>
<td>0.18</td>
<td>36.5</td>
<td>6.57</td>
</tr>
<tr>
<td>Total</td>
<td>0.335</td>
<td></td>
<td>155.125</td>
<td>27.92</td>
</tr>
</tbody>
</table>

Therefore, the total expenditures of the community accounted for household use is calculated in the following table; see Table 60.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total Households</th>
<th>Total Expenses (USD)</th>
<th>Total Annual Expenses (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household</td>
<td>110</td>
<td>27.92</td>
<td>3071.2</td>
</tr>
</tbody>
</table>

Finally, after assessing the load, consumptions and expenses at the different levels, an overall view of the total community expenditures for whole system, working at the load factor mentioned before in Figure 35, is shown in Table 61.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Annual Consumption (kWh)</th>
<th>Annual Expenses (USD)</th>
<th>Annual Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productive Use</td>
<td>4682.79</td>
<td>636.86</td>
<td></td>
</tr>
<tr>
<td>Household</td>
<td>17063.75</td>
<td>3071.2</td>
<td></td>
</tr>
<tr>
<td>Community Service</td>
<td>8132.2</td>
<td>1463.80</td>
<td></td>
</tr>
<tr>
<td>Mini-grid Battery Charg.</td>
<td>2452.8</td>
<td>441.50</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>5613.36</td>
</tr>
</tbody>
</table>

As can be seen in the Table 61, the annual expenditure of the overall system, including all the users and under the specific configuration defined in the beginning of this section is 5613.36 USD. The given data could be use to perform a feasibility study of the project’s functioning.
6. Conclusion and Recommendations

In Uganda, rural development is one of the government priorities, with the prerequisite of the productive activities being clearly stated. On the one hand, the government is committed to this issue by supporting the institutes or related studies, which are organized by the ministries. On the other hand, the private sector, entrepreneurs and NGOs are the other driving forces of this development. In this matter, this project has a noteworthy position between all these players. Pamoja Cleantech AB had started the business by having the collaboration with UIRI (Uganda Industrial Research Institute) and Makerere University and they have developed new collaboration with the long-standing NGOs. Besides, the interest of the private sector cannot be disregarded, for instance, the role of the telecom companies. Thus, the Green Plant project is promising to cover different expectations from a range of stakeholders.

As a part of the GP project, this thesis work has been started in order to find out the best possible ways of satisfying the needs of the community in the rural areas by using the energy surplus of GP. The authors present the conclusions based on the research question that has been formulated in chapter 1.

In financial terms, it is important not only to quantify the required but also to identify the business stakeholders, who to sell the energy surplus, how to sell it and how to use the Green Plant more efficiently. In this case, the researchers identified the telecom companies as important actors of the GP concept. As has been mentioned before, the telecom companies are excluded from the scope of the thesis work. However, telecom companies will be the key partner for the implementation of the GP as they ensure the cost-efficiency balance and continuity of the system. Therefore, one of the applications of the system would allow charging the cell-phones more easily, thereby; thus, the rate of mobile usage is expected to increase. In this sense, GP offers a win-win possibility in which communities and companies gain some benefits.

From the economical perspective, the capital investment of the suggested final product, including the three developed applications, is unvarying. The current energy consumption levels and the related expenses are shown in Table 62.

<table>
<thead>
<tr>
<th>Current Energy Consumption</th>
<th>Annual Consumption</th>
<th>Cost</th>
<th>Annual Expenses (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>132.5 litres</td>
<td>1.06 USD/litre</td>
<td>104.5 USD</td>
</tr>
<tr>
<td>Diesel</td>
<td>1200 litres</td>
<td>1.06 USD/litre</td>
<td>1272 USD</td>
</tr>
<tr>
<td>Firewood</td>
<td>1095 bundle</td>
<td>0.35 USD/bundle</td>
<td>383.25 USD</td>
</tr>
<tr>
<td>Charcoal</td>
<td>16 bag</td>
<td>5.33 USD/bag</td>
<td>85.28 USD</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1845.03 USD</td>
</tr>
</tbody>
</table>
Remembering the budget shown in the Figure 30, it is possible to estimate the payback time of the implemented applications. It is important to know that these calculations are done based on the business as usual scenario, which is assuming that the consumption trends are kept. The payback time would be about 24 years, see Table 63. This scenario considers that the production rate remains the same and there are no investments on any machinery which would affect the income level. However, the authors think that this scenario is not likely to happen due to the will to increase productive activities shown by the community during the interviews.

<table>
<thead>
<tr>
<th>Total Cost of the System</th>
<th>Current Energy Expenses</th>
<th>Payback Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>44182.80 USD</td>
<td>1845.03 USD / Year</td>
<td>24 Years</td>
</tr>
</tbody>
</table>

Another scenario has been developed based on the electricity tariff defined by Pamoja AB, 0.18 USD/kWh. The expected annual revenue is calculated based on the demanded power of the machinery for the productive activities and the estimated annual consumption in households and community services. These data can be found in the previous section of this report (Section 5.3.2 Final Layout of the System). The estimated payback time in this case is about 7 years; and is shown in Table 64.

<table>
<thead>
<tr>
<th>Total Cost of the System</th>
<th>Expected Annual Revenue</th>
<th>Payback Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>44182.80 USD</td>
<td>5613.36 USD / Year</td>
<td>7.8 Years</td>
</tr>
</tbody>
</table>

The results shown in Table 64 include the expected economic development of the community. As an example, implementing the final life-solutions would add value to the coffee production, allowing the farmers to process their crops by themselves and increase their income. Table 65 shows how the price of the product increases as its quality is raised by further stages of processing.

<table>
<thead>
<tr>
<th>Product</th>
<th>Price of the Coffee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Coffee Fruit</td>
<td>0.7875 USD / kg</td>
</tr>
<tr>
<td>Dried and Husk Removed Coffee</td>
<td>1.6101 USD / kg</td>
</tr>
</tbody>
</table>
It is important to highlight that the payback time estimations do not include the participation of the telecom companies. This means that payback period would be significantly reduced by the inclusion of this stakeholder.

Final Comments and Recommendations

This final product ensures that these three life-solutions will be well accepted and provide most benefit for the community. The community also needs an increase on the productive activities at the area. The provided life-solutions must cover these need and the business approaches must be accepted by the society. Hence, the final product, which means three chosen life-solutions, ought to work for the community, by the community and also satisfy the economical concerns of the stakeholders. Detailed analyses of the possible life-solutions are given in section 4.4 Applications and Life-Solutions. The table 10 and Table 11 show the possible practice of the applications. Furthermore, the final product is developed regarding to those potential applications.

As it has been stated before the life-solutions concept does not only aim to cover the electrification issue but also socio-economical development. According to the field studies, the community gives high importance to these life-solutions and also the productive activities are important for them. It means that the final product should foster productive activities and at the same time this economical growth must come up with a positive impact on the social level of the society. The mini-grid application is of importance in terms of having a positive socio-economical impact on the society. The section 5.2 Potential Impact Identification of the Selected Solutions gives details of the product very clearly. The electrification will drastically change the communal and household lighting situation, machinery usage for productive activities, and also social activities. The main impacts can be listed as following:

- Reduction in consumption of expensive fuel. The price of diesel is much higher than the energy supplied by the GP
- The spread of electricity all along the community would increase inhabitants’ possibilities and with the likely enlarged economical activity, a growth in community consumption of energy.
- The delivery of electricity and lighting to the households could mean the possibility for the students to do their homework, readings and other educational activities for longer hours and at their own places. Thus, improving educational level in the area
- The empowerment of agricultural production and activity could mean feeding self-sufficiency, guaranteeing the feedstock and the market possibilities during bad-cropping seasons.

While the electrification changes the social life, at the same time the new possibilities will attract the telecom companies. At the moment, the inhabitants do not have lighting but they already have mobile phones which are waiting most of the time to get charged. This is why the companies are expected to be interested in this kind of establishment.
Interestingly, the battery charging stations appear to be a very relevant life-solution to the community. This is because not only a leisure activity but also productive activities depended on the availability of mobile services. In this particular case, the communication industry acts as a driving force for the development of rural electrification. Based on a common interest, this project promotes a positive socio-economical impact on the community.

The environmental concerns are always of importance while working on sustainability and aiming at achieving a sustainable solution. So, was it in this thesis projects as well. The renewable energy production solutions are the key elements of the sustainability solution as all can agree on. Here in this project a gasification system is used in order to achieve this environmental friendly solution. Local resources are used and therefore the project is promising for CO₂ neutral system. Moreover, the system is designed as decentralized and local solution in order to maintain this environmental solution and be able to use it more efficiently which means that the input of the system are the local resources.

Another important environmental aspect is the cradle-to-cradle approach which we used to include into the final product phase. Dealing with the waste is always a challenge in terms of environmental concerns. The authors have always been aware of this situation and they have been acting accordingly. One of the solution approaches involved the cradle-to-cradle approach to be able to decrease negative environmental impacts of the final product and to use all the resources more efficiently. For this reason, the biochar solution has been one of the first possible applications which have been studied during the research phase. The biochar application has been taken into consideration with the purpose of closing the loops and at the same time achieving a cradle-to-cradle approach which uses the waste of the system as a by-product and increase the yield of the agricultural activities. The details are shown in section 2.3.1

In terms of achieving a reliable solution and making it sustainable for rural areas in developing countries, project developers need to keep the key life-solutions in mind and design the project to be well accepted by the locals. Hence, the challenge for the GP concept in Uganda is to use a western technology adapted for the locals, according to their needs so that the solution is well accepted by the inhabitants.

The field work which has been performed incorporation with NGOs and cooperatives has shown the importance of community participation. NGO and agricultural cooperatives know the local reality. They have contributed to increase their liability and consistency of our results. According to our observations and MCDA, the a product comprising Mini-grid, Battery Charging Station and a heat pipe exchange has been identified as essential to implement the GP in an efficient and beneficial way considering stakeholders' views.
To summarize, this thesis work shows the challenges that Uganda faces in relation to life-solutions and energy provision. The ultimate goal was to come out with an idea which uses the surplus energy from a decentralized small-scaled power plant in order to provide sustainable life-solutions. We selected three applications that have the potential to achieve this goal, which are; 1) Mini-Grid, 2) Battery Charging Stations and 3) Heat Pipe Exchangers. These three applications address all three aspects of sustainability.

- The research has shown the great potential of the GP project to Pamoja AB. It has highlighted the relevance of bringing different stakeholders together in a most effective way according to their common interests.
- The research also gives a significant importance to the environment and establishes a complete system which ensures to satisfy the economical and environmental concerns at the same time. In this manner, we can all see that it is very possible to achieve a business point which improves the productive activities and financial incomes and still be respectful to the environment.

The validation of the results could always be enhanced by increasing the number of the cases in different places (preferably different countries).

The authors would like to finalize the report with pointing out the possible future research that could be done. There are numerous ways of varying the life-solutions by using different applications. However, there are some limitations such as financial or technical inadequacy. The future research could include all those eliminated appliances and try to create a more effective system. Separately, the possible impact assessment that is done during this research could be performed after kicking off the system in the pilot site. Or even more, the similar study could be performed for different places to collect more data and increase the efficiency of the system. Besides, the capacity of the GP was also a limit for the project. Thus, with a bigger system, it could be enriched the life-solutions.
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Appendices

Appendix I The Absorption Chiller Working Process

The functioning of the absorption chiller is relevant in order to understand how should it be applied in case it is selected as a possible output for the thesis work. The Figure I shows the different parts involved in the system. Then, to facilitate the comprehension of it, an explanation of the process is also done.

Two different fluids perform the cycle of the absorption chiller; one is called refrigerant and the other is called absorbent. The most commonly used combinations of fluids are water-lithium bromide or ammonia-water, refrigerant and absorbent respectively. In order to understand the procedure of the system, the explanation will start from the absorption cycle (Combined Heat and Power, 2007).

- In the absorption cycle the two fluids are combined and then separated. The low-pressure refrigerant vapour that arrives at the absorber is combined with the absorbent; this process releases a big amount of heat. The solution of the two fluids is pumped into the generator that works at high pressure. In this point the heat, which is being reused, is added to the process. This heat produces the evaporation of the refrigerant and the subsequent separation of the two fluids, the refrigerant in vapour and the absorbent as liquid. In this point, the absorbent is leaded to an expansion valve before going back to the absorber by the pressure difference, meanwhile the vapour refrigerant flows to the condenser.
- The high-pressure vapour refrigerant in the condenser rejects the heat and becomes high-pressure liquid.
- The next step is to transform this high-pressure liquid into a low-pressure fluid. An expansion valve that is placed right after the condenser performs this process.
- Once we have the low-pressure liquid it is leaded into the evaporator. In order to perform the evaporating process at low pressure, the liquid absorbs an amount of heat that creates the cooling system by a heat exchanger. Right after

Figure I. Absorption Chiller, Working Diagram (Gordon & Choon, 1995)
converting the fluid into vapour it is driven again into the absorber where the cycle starts again.
Appendix II The ORC Turbine Working Process

The functioning of the ORC turbine is relevant in order to understand how should it be applied in case it is selected as a possible output for the thesis work. The Figure II shows the different parts involved in the system. Then, to facilitate the comprehension of it, an explanation of the process is also done.

The process on going within the system is easy to understand. It is based in five basic components, these are: the working fluid, the evaporator, the turbine, the condenser and the pump (Yamamoto et al., 2001). The diagram (Fig. 8) shows how the system is distributed. The process starts in the evaporator where the waste heat recovered transfer the thermal energy into the working fluid evaporating it at a high pressure. The flow is directed to the turbine in which is transformed into mechanical power. The working fluid, during the process in which it transfers energy to the turbine, suffers a drop on the pressure. The low-pressure vapour is introduced in the condenser in which will exchange heat with another fluid and turned into liquid. In the last step of the process the working fluid is pumped to the evaporator again, in which the cycle begins again (Wei, et al., 2007).
Appendix III Field Trip – Identification of Potential Sites

The collection of relevant data, for the analysis of the potential locations for the GP, is done by filling the following form:

Visit to: *(Name of the area, village, community, etc.)*

1. **Area**
   1.1. Geographical placement
   1.2. Extension of the village, community, town. *(Approximate distances)*
   1.3. National grid expansion possibilities

2. **Population**
   2.1. Households
   2.2. School covering
   2.3. Economical level *(possibilities of consumption, will of payment, capacity of acquiring devices which need of energy, etc.)*

3. **Industrial/Commercial/Social activities**
   3.1. Main activity
      3.1.1. Industrial *(Cooperatives, farms, mills, etc.)*
      3.1.2. Commercial *(Markets, stores)*
      3.1.3. Social *(Schools, cultural houses)*
   3.2. Energy consumption per sector *(estimated)*
      3.2.1. Industrial
      3.2.2. Commercial
      3.2.3. Social
   3.3. Population involved in these activities
   3.4. Further possibilities *(cooperative creation, implementation of other activities, such milling if there is not currently existing)*

4. **Current energy resource(s)**

5. **Biomass supply possibilities** *(agricultural activity)*
   5.1. Amount of activity *(possible cover plant needs)*
   5.2. Type of crop

6. **Social energy requirements**
   6.1. Households *(cooking, light, etc.)*
   6.2. Community needs *(milling, water pumping, feedstock conservation, medicines, etc.)*
   6.3. Other needs

7. **Conclusion**
Appendix IV Weighted Product Model Example

The best way to understand how the WPM is applied and work, is to explain an example from the beginning to the end. The WPM is a matrix-based system where the criteria and the alternatives are operated in order to obtain the best alternative; this means the alternative which better covers the criteria needs in a global approach, according to the weight criteria applied.

In the Equation I, it is described how the different alternatives are assessed depending on the criteria and its weight, it shows the mathematical procedure to obtain the final result (Bridgman, 1922 and Miller & Starr, 1969 cited in Triantaphyllou, et al., 1998, p. 5):

\[ R(\frac{A_K}{A_L}) = \prod_{i=1}^{N} \left( \frac{a_{Kj}}{a_{Lj}} \right)^{W_j} \]


Where:

- \( A_L, A_K \) are the actual values of performance of the alternatives.
- \( N \) \( \rightarrow \) number of criteria;
- \( a_{Kj} \) \( \rightarrow \) is the actual value of the \( i \)-th alternative in terms of the \( j \)-th criterion;
- \( W_j \) \( \rightarrow \) is the weight of importance of the \( j \)-th criterion.

If:

\[ R(\frac{A_K}{A_L}) > 1 \; ; A_K \text{ is better than } A_L \]

As example;

For the project work it is need to decide between the alternatives \( A, B, C \); knowing that the most important criteria to take in account in \( Z, Y, X \). It is stated that the weight of the criteria is:

\( Z = 0.4; \quad Y = 0.35; \quad X = 0.25 \)

The Figure III shows the alternatives, the criteria and how each alternative performs the criteria one per one:

<table>
<thead>
<tr>
<th></th>
<th>Z</th>
<th>Y</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>23</td>
<td>19</td>
</tr>
</tbody>
</table>

Figure III. Example on filling a MCDA chart
Following the Equation II, which is the application of Equation I into this specific case and ranking A/B:

\[ R\left(\frac{A_K}{A_L}\right) = \prod_{i=1}^{N} \left(\frac{a_{K_i}}{a_{L_i}}\right)^{W_i} = \left(\frac{A_Z}{B_Z}\right)^{0.4} \times \left(\frac{A_Y}{B_Y}\right)^{0.35} \times \left(\frac{A_X}{B_X}\right)^{0.25} \]

Equation II. Evaluation of Alternative A and B

\[ R\left(\frac{A}{B}\right) = \left(\frac{15}{4}\right)^{0.4} \times \left(\frac{20}{30}\right)^{0.35} \times \left(\frac{8}{2}\right)^{0.25} = 2.0820 \]

; so

\[ A > B \]

The result obtained shows that for the specific purpose the alternative A cover the criteria requirements in a better way than B. Then;

\[ R\left(\frac{A}{C}\right) = 0.7131 \quad R\left(\frac{B}{C}\right) = 0.3425 \]

and so it is easy to rank the alternatives as;

\[ C > A > B \]

C is the best alternative.

Ranking in the study case

The way in which the classification will be done is following the example previously given. The main difference between the example and the study case remains in the quantity of alternatives. It is obvious that is easier to rank the options as less there are, but in the case under study the different possibilities will be compared following the numerical order. Thus, the first will be compared with the second; the most promising of those will be compared with the third and so on. The result out of all the comparisons made will be the guide that will be used to rank the alternatives.
Appendix V Brochures, Catalogues and Relevant Data related to the Possible Applications Assessed in the MCDA

The Heat Pipe Exchanger Model can be seen in the Figure IV

Figure IV. Heat Pipe Exchanger Characteristics
The ORC Turbine Brochure can be seen in Figure V.

**INFINITY TURBINE ®**

**2010 MODEL IT10 Organic Rankine Cycle**

**IT10 Frame Enclosure Version Only - 2010 Modular Turbine**

<table>
<thead>
<tr>
<th>Description</th>
<th>Frame Mounted DC or AC Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Power Output (Based on R245fa Genetron)</td>
<td>10,000 Watts (10 kw)</td>
</tr>
<tr>
<td>Generator (add on) Direct Shaft Drive 1,800 - 3,600 RPM</td>
<td>Optional DC or AC 50/60hz</td>
</tr>
<tr>
<td>Evaporator Flow - gpm</td>
<td>24-32 gpm @ 120 C - 80 C</td>
</tr>
<tr>
<td>Condenser Flow - gpm</td>
<td>40-80 gpm @ 15 C - 36 C</td>
</tr>
<tr>
<td>BTU Input (based on 35,000 - 40,000 btu/kw heat rate)</td>
<td>400-600,000 btu/hr</td>
</tr>
<tr>
<td>Frame Version Only - Dimensions (uncrated) and Weight 2 x 4 x 4 ft (800 lbs) approx.</td>
<td>510 mm x 1220 mm x 1220 mm (383 kg)</td>
</tr>
<tr>
<td>Operating Sound (Depends on Working Fluid)</td>
<td>40 dBA or less @ 10 m (33 ft)</td>
</tr>
<tr>
<td>Inlet and Outlet Pipe Sizes</td>
<td>2 inch (51 mm)</td>
</tr>
<tr>
<td>Application Considerations</td>
<td>Direct Shaft Drive</td>
</tr>
<tr>
<td>Time to Manufacture Turbine Only (approximate)</td>
<td>1-3 weeks</td>
</tr>
<tr>
<td>IT10 Plans and Consulting</td>
<td>$5,000</td>
</tr>
<tr>
<td>Screw Turbine ® Only (for steam, refrigerant, etc.)</td>
<td>Approx $15,000 - Market Price</td>
</tr>
<tr>
<td>Parts</td>
<td>Email for List</td>
</tr>
</tbody>
</table>

The Infinity Turbine IT10 is experimental and designed for 80-120C input waste heat (liquid form).

Figure V. *The ORC Turbine Characteristics*
The model of the Absorption Chiller used is shown in Figure VI.

The ORC Turbine Characteristics

Figure V. The ORC Turbine Characteristics
Appendix VI VI-Skogen Questionnaire – Site Visit

**Information Data:**
1. Name of Institution/Village and purpose: ____________________________
2. Name of Interviewee and contact: ________________________________
3. Position in the institution/village: ________________________________
4. Date of Survey: ________________________________
5. District: ______________ Sub-county: __________ Parish: ____________
6. Village: ________________________________
7. How many people are hosted in your institution/village? ______________

**Demand assessment:**
1. How many meals are prepared per day (incl. Breakfast, lunch and dinner)? ____________
2. How many hours do you spend cooking per meal?
   - Breakfast ___ h, lunch ___ h, dinner ___ h
3. How much fuel do you use every time you cook? ________________________________
4. Does the institution/village boil drinking water? YES/NO
   - If YES, how much water and how often? ________________________________
5. How big are your cooking pots?
   - Between 5L and 15L _______ between 15L and 50L _______ over 50L _______
6. How many rooms do you light during night? ________________________________
7. How many hours do you light these rooms? ________________________________
8. Do you currently use solar power? YES/NO
   - If YES how big is the system? ________________________________
9. How much money do you spend on energy per month or year?

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Usage (units / time)</th>
<th>Unit Cost (UGX / unit)</th>
<th>Cost each transport (UGX)</th>
<th>Purpose e.g. cooking, lighting, boiling, charging, productive use, radio etc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerosene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Candles</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Charcoal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cow dung</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative energy source (specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. Questions about your energy supply?

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Where to get your energy source?</th>
<th>Distance to supply location?</th>
<th>Difficulties in energy supply</th>
<th>How do you store the energy fuel?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery</td>
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<tr>
<td>Kerosene</td>
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<tr>
<td>Candles</td>
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<tr>
<td>Charcoal</td>
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<tr>
<td>Firewood</td>
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</tr>
<tr>
<td>Biogas</td>
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</tr>
<tr>
<td>Cow dung</td>
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<tr>
<td>LPG</td>
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</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative energy source (specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. How was the trend of your energy demand in the last 5 years? ________________
12. What is the expected increase of the population in the next 2 years? ____________

Possible alternative fuels
1. How do you manage waste (kitchen, agriculture and excrements)? (e.g. pit-latrine, compost, fertilizer)____________________________________________________
2. Does your institution/village own an agricultural farm? YES/ NO
   if YES, what type of agricultural farm?____________________________________
3. How big is your farm? (e.g. 10 cows, 30 pigs, xx chicken, crops, trees, fruits etc.) ________________________________
4. What agricultural practices are in place? ____________________________________
5. What is the source of water supply? ________________________________________
6. Do you have access to agricultural wastes (e.g. maize cobs, rice husks, charcoal fines, grass, papyrus or cutting wood)? YES/ NO
   If YES, what kind of wastes? _______________________________________________
7. How much waste would you be able to collect in a week______________________
8. How much would it cost?______________________________________________

Environmental awareness:
1. Have you ever heard of Environmental degradation or Global warming? YES/ NO
   If YES, what are you doing for / against it?_________________________________
2. Are you currently using energy efficient technology to burn fuels? YES/ NO
   If YES, which technology?___________________________________________________
3. Have you ever participated in any Environmental awareness campaign? YES/ NO
   If YES, which campaign (e.g. tree planting)?_________________________________
4. Would you be willing to use modern technologies to conserve the environment (e.g. biogas, gasification, rainwater harvesting, composting, organic farming, beekeeping, waste collection)? YES/ NO

If YES, which technology and how much are you willing to spend extra?________
Appendix VII Data Summary for the MCDA Chart

The data shown is the one used to fill the MCDA chart. It is a sum of the data extracted from the field trips and the information of the brochures and the working characteristics of each of the applications assessed. The compilation adds facts from the sections 4.3 Pilot Area and 4.4 Applications and Life-solutions; as well as from the Appendix III, V and VI). It is easy to see that the data has been arranged following the different criteria that are analyzed in the MCDA. For each studied application there is a description and a definition of the data to be used in the MCDA chart.

1. Biochar

As it has been mentioned before the biochar is one of the main outputs of the system. Thus, the biochar is produced continuously during the gasification process. The importance of this application as fertilizer is coming from that it is a key example for the cradle-to-cradle approach. The expected business model is to sell biochar back to the farmers’ cooperative, which the Pamoja Company buys the biomass from.

- Economical Cost: There is no an extra investment cost for this application since the biochar is produced as an output. However, to be more specific, the operational cost of collecting biochar could be added (it is excluded in this study)
- Economical Benefit for Pamoja Cleantech: The price of the fertilizer could be set according to the chemical based fertilizer market prices. On the other hand, charging the farmers for biochar could decrease the willing of applying the fertilizer. Hence, the application could start with a pilot project to see the results and benefits of the application to convince the farmer cooperative. Or another alternative could be an agreement between the cooperative and Pamoja which sets a relative discount on the biomass input.
- Development Empowerment: The fertilizer would increase the yield of the product. Thus, the farmers would have more goods in the end of the harvesting seasons. From the field trips, the researchers know that the farmers would like to apply fertilizer but in the present, they cannot because of the high fertilizer prices.
- Population Coverage: The amount of people affected by this system would be the entire farmer cooperative, 100% of the cooperative members.
- Electricity Consumption: There is no electricity consumption neither for producing nor applying the biochar.
- Environmental Care: As it has been mentioned in the section 2.3 The Green Plant and the Potential Applications, the biochar application is very effective on the yield and it eliminates the negative environmental impacts of the chemical based fertilizers.
- Life-spend: For this application it was complicated to define the life-spend. The number of the harvesting season during one year could be a base line; however, it would
not give a fair comparison with the other alternative. Hence, the authors have decided to give the lowest grade for this application by considering that the farmers need some time to see the agricultural benefits after applying the soil amendment.

2. **Mini-Grid**

The electricity is the major output of the system. The GP will provide electricity for the telecom tower and for the community. A device, so called “off-grid inverter”, will perform the power management of the system. The main system components are the batteries, which are charged by the GP output and the inverter, which reverts the alternative current network into direct current to charge the batteries. The households are connected to the GP by the mini-grid. The entities of the MCDA chart is filled based on this off-grid inverter

- **Economical Cost: 9700 USD**
  - Initial Investment:
    - Off-grid inverter: 2600 USD
      - Technical details:
        - AC output: 230/250 V 50/60 Hz
        - AC input (generator): 230 50/60 Hz
        - Dimension (W/H/D): 450 / 425 / 165 mm
        - Weight: 23 kg
    - 6 batteries: 4470 USD
      - Technical details:
        - Battery DC input: 24 V 90 A
        - Battery type: Lead / NiCd
        - Battery capacity: 100 Ah....1000 Ah
    - Other (power management system devices): 2630 USD

- **Economical Benefit for Pamoja Cleantech:**  
  The budgeted price for electricity selling is set to 0.52 USD/kWh for the telecom company and 0.25USD/kWh for the community by Pamoja AB. This application is one of the most economical beneficial applications for the company.

- **Development Empowerment:**  
  The rural electrification problem may be the most crucial issue of lacking basic human needs. To avoid this problem would have a significant impact on society’s development. This application would make lightning possible at home, allow using telecommunication opportunities (mobile phone charging, radio, tv etc.) and a leading fact, it would make educational options increase. In addition, it would make to run some business activities such as electrifying the shops, running machinery equipments, etc.

- **Population Coverage:**  
  Different then the major part of the application, instead of concerning just the farmers, this application covers different part of the community and also households.

- **Electricity Consumption:**
From the nature of the application, the usage of energy to charge batteries does not take into account as electricity consumption.

- Environmental Care:
  One of the alternative solutions of the supplier is to use lead-acid batteries. The lead is a recyclable material but yet it is extremely toxic. Even a small amount of exposure can cause brain and kidney damages. The supplier did not provide any information about the lifetime of the batteries but we could assume it as same as the lead-acid car batteries, which is three years.
  The other option is to use nickel-cadmium (NiCd) batteries. Industrial NiCd batteries contain 6% cadmium, which is a toxic heavy metal. The accumulation can cause a significant pollution. This fact makes the situation more sensitive and therefore the disposal part requires a special care.

- Life-spend:
  The supplier did not provide any information about the life-spend of the system either. However, an estimation can be done by looking at the warranty issues. The supplier provides a free warranty during first 5 years, and then it could be prolonged for 10 to 15 years optionally. So, the input value for the MCDA chart is taken as 15 years (excluding the battery replacement issue).

3. BCS
The battery charging system has two main components. The first one is the rectifier, which is an electrical device that converts alternating current (AC) to direct current (DC). The rectifier transfers AC after the generator to DC in order to charge the batteries. The second device is coming right after the rectifier, the charge controller. This equipment is used to ensure that the system is working, and protect the system against overloads (this would protect the batteries and the generator). An overview of the system is given below, see Figure VI;

![Figure VI. BCS Conceptual Layout](image)

Economical Cost:
The main device of the system is the microprocessor controlled rectifier/battery charger. The equipment, either single-phase or three-phase systems, is designed
to supply DC power to sensitive loads at a constant uninterrupted voltage, free from the usual utility power line distributions.

- Initial Investment:
  - The charger: 340 USD

- Economical Benefit for Pamoja Cleantech:
  The budgeted price for electricity selling is set to 0.52 USD/kWh for the telecom company and 0.25 USD/kWh for the community by Pamoja AB. This application is one of the most economical beneficial applications for the company.

- Development Empowerment:
  The rural electrification problem may be the most crucial issue of lacking basic human needs. To avoid this problem would have a significant impact on society’s development. This application would make lightning possible at home, allow using telecommunication opportunities (mobile phone charging, radio, tv etc.) and a leading fact, it would make educational options increase.

- Population Coverage:
  Different then the major part of the application, instead of concerning just the farmers, this application covers all the community and households.

- Electricity Consumption:
  From the nature of the application, the usage of energy to charge batteries does not take into account as electricity consumption.

- Environmental Care:
  The system is designed to run with lead-acid batteries (12V, 40-70 Ah). These are the same batteries that the community is already using these batteries with diesel generators or national grid. One material issue related to the environmental aspect, is the disposal phase. Most of the suppliers indicate the lifetime of a car battery as three years. The stakeholders should take into account this fact and pay attention on disposal and recycling systems. The lead is a recyclable material but yet it is extremely toxic. Even a small amount of exposure can cause brain and kidney damages. On the other hand, recharging batteries would decrease the use of the dry cell batteries, which are thrown into the nature after being used.

- Life-spend:
  The supplier did not provide any technical data on the life-spend of the charger. But the estimated life span of the batteries is around 6 or 7 years.

4. The Heat Pipe Exchanger

Taking in account that the coffee dry process is done by natural heat, that means sun-heat, it takes a long time and, what is more important, this time is unpredictable due to the uncertainty over weather, especially during the rainy season that is when the harvest is done.

The possible use of heat just by extracting the hot air from inside the container and stream it where the coffee is, and by this reduce the drying time considerably, could be an efficient and cheap way to improve the actual coffee drying process. This process
could help to cool down the temperature inside the container, and by that reducing possible harm to the operators and the machinery.

- **Economical Cost:** \(2,820 + 73.93 = 2893.93\) USD.
  - **Initial Investment:**
    - The price of the device is 2,820 USD.
  - **Maintenance:** Total cost 73.93 USD
    - Annual electricity consumption cost for the functioning of the device is 8.73 USD.
    - Possible repairing. 120 USD every 4 years for fans’ replacing.
    - The estimated maintenance cost by the company is 65.2 USD.
    - 5-year warranty included in the purchase.

- **Economical Benefit for Pamoja Cleantech AB:**
  - There is not defined direct profit out of this activity;

- **Development Empowerment:**
  - Reduction in drying time, this fact allows to control the production and to have beforehand the timing of each step of the process, therefore there is a better planning and a more efficient work. It won’t promote directly any development or create any job, but the capacity of predicting when the harvest is going to be ready to process let the people get ready and stay on step further than now.

- **New Business Opportunity:**
  - The implementation of this system can empower the farmers to increase coffee production and so, whether more people will be related to farming or current farmers will hire people to help them increase their yield.

- **Population Coverage:**
  - The amount of people affected by this system would be the one that is currently producing coffee. In the village where the pilot plant is placed 70 households over a total of 110 are dedicated to coffee crop, which means almost 65% of the total population is dependent on this activity.

- **Electricity Consumption**
  - The amount of electricity consumed for the functioning of the device, it is up to 44.16 kWh/y.

- **Environmental Care:**
  - The material used in this system is mainly aluminium, which is cheap and easy to recycle. The heat pipes which have alcohol inside, small quantity of it, do not have to be replaced until the system is replaced, which means more than 10 years of use. That makes the system not very harmful for the environment.
  - The level of noise is between 58 – 62 dB. It is the same grade of noise than the sound of a full restaurant.
  - The sustainability of the system could be improved by the use of the heat in other tasks apart than drying the coffee. Thus, shorten the payback time and add extra value to the whole concept.
  - The cooling capacity of the system is up to 2.19 kW, taking in account that the estimated heat load in the container is 12.126 kW is supposes a recovery of almost 20% of the heat. Thus, it can be stated as good performance.
• Life-spend:
  The estimated lifetime work of the device is above 10 years, although the
  moving parts of it (fans) should be replaced every 4 – 5 years.

5. Recuperator
The recuperator is a heat exchanger device, as the heat pipe, it could be used in many
applications, mainly improving the coffee drying system or drying the biomass input in
the hopper, among other possibilities.
The efficient recovery of heat by using this system is not possible because the quantity
and quality of the heat source does not reach the desired level for this kind of device.
Therefore, the application of this system is not feasible in the Green Plant. It is discarded
for the MCDA.

6. Absorption Chiller
The output of the absorption chiller is a cool fluid. This fluid could be used to refrigerate
other fluids or, in few cases when it works almost ideally, its cooling service chills some
food products for a longer preservation. In the study case, the non-continuous
functioning of the gasifier automatically discards this option. Thus, the cooling system
would be used as a refrigeration application for any machine or even for the Green Plant
itself, or other device applied to the system, as battery charging.
• Economical Cost:
  o Initial Investment: 45,183.26
    ▪ Purchase Cost USD.
  o Maintenance:
    ▪ Cost of electricity consumption USD.
    ▪ Possible repairing (likely following brochure)
    ▪ Warranty; No data
    ▪ Other cost.
• Economical Benefit for Pamoja Cleantech AB:
The direct benefit for Pamoja would be the selling of the cooling service to the
community, for shared purposes, selling the service to a micro-enterprise or to
the households that could afford it.
• Development Empowerment:
  One of the most likely uses of the cooling service is short storage of milk and
food products, and the locals declared during the surveys, the storage of milk,
even for 1 or 2 days, can imply an arise of product prices, and directly increase
the revenues of the producers.
• New Business Opportunity:
  There is no possible creation of new business because it would be Pamoja, the
actor who is selling the service directly to a customer, is not selling energy to
facilitate the implementation of new business in that direction.
• Population Coverage:
The whole cooperative would be benefited if the milk business increases its
revenues, 100% of the members of the cooperative. The cooling service would
be available to all those customers that will to pay for the service, but at first sight is open to everybody.

- **Electricity Consumption:**
  The electricity consumption is mainly related to the hours of service, but as a cooling service, it is supposed to be working 24 hours a day, everyday of the year. Supposing that the storage is done for 10 months a year, full load and 24 hours a day, the consumption of electricity per year would be:
  - Power input: 0.072 kW.
  - Working 24 hours per day: 1.728 kWh/day.
  - And under the working regime described before: 518.4 kWh/year.

- **Environmental Care:**
  The principal positive factor of this system is that it uses recovered heat to produce cooling service. It is re-using waste energy and so, it is an environmental-friendly device.

- **Life-spend:**
  There is no data related to the life-spend of the product, and so, it will be negatively graded in order not to overrate it.

7. **Organic Rankine Cycle Turbine**

   The ORC Turbine is used to produce a mechanical movement, to transfer it to a shaft, after the recuperation of thermal energy. This system is still under experimentation and constant improvements. Despite of this, the immediate future of this application is promising, and that reason pushed the researchers to include this system into the project.

- **Economical Cost:**
  - Initial Investment: 15000 USD + Bad maintenance conditions.
  - Maintenance:
    - Cost of electricity consumption: 0 USD.
    - Possible repairing: Likely of failure due to the fact that it is still under development.
    - No Warranty.

- **Economical Gross Benefit for Pamoja Cleantech AB:**
  There is a very likely benefit for the company as the service can be potentially sold to the cooperative.

- **Development Empowerment:**
  The farmers that could benefit of this service would significantly increase their revenues by adding value to its product (further processing). It would also have a positive impact on local economy and in the cooperative expanding possibilities.

- **New Business Opportunity:**
  It will probably foster the creation of new jobs in the coffee and maize processing activity as it is improved by the application. May be new machinery can be purchased and other agricultural activities can be started taking advantage of the possibility that using mechanical power brings.

- **Population Coverage:**
  Farmers that crop coffee and maize would benefit of the mechanical power
produced by the ORC turbine because it would drive the mills.

- **Electricity Consumption:**
  - There is no electricity consumption for the functioning of this device. It works with the waste heat of the exhaust gas.

- **Environmental Care:**
  - The material used for the construction of the ORC turbine is mainly stainless steel. The noise level is less than 40 dBA at 10 meters of distance. The fact that the energy is coming from the re-use of waste energy makes this application very environmental-friendly.

- **Life-spend:**
  - No data given by the producer. No estimation as it is a new product that is still under experimental stage.
Appendix VIII Mini-Grid Design, Technical Data and Calculations.

The stages done in this appendix could be listed as a continuation of what is done in the report, section 5.2.1 General View of the Application, in the mini-grid case. In the report, the last step done is the “III. System Layout”. Therefore, the explanation will continue from this point.

IV. Line configuration
After assessing the different possibilities for the line configuration, and due to different reasons that are stated below, the final election has been to apply a three-phase four-wire (wye) configuration.

- Ugandan nominal voltage is 240V. Three-phase configuration allows the connection to this voltage, and so, most of the items and devices could be connected to the mini-grid without the need of any change.
- Three-phase configuration is cheaper because it uses less conductor material to transfer the same voltage than the equivalent in other configurations.
- Three phases can be split into single phases for household and community usage for low voltage.
- Allows the connection to larger demanding equipment.

V. Conductor
a. Type of conductor
The conductor type selected for the mini-grid distribution line is: Aluminium Conductor Steel Reinforced (ACSR) (Inversin, 2000; Suwannakum, 2008). The main characteristics of ACSR are:

- It’s conductivity properties are lower compared to copper. Aluminium needs 1.6 times the area for same conduction.
- Smaller weight per unit length than copper, it allows to implement longer spans and so, potentially use fewer poles, related economical savings.
- To increase its strength it can be wrapped around a steel core to obtain steel-reinforced ACSR, which is the most widely used conductor for lines.
- Special care has to be taken when it comes to the use of it crossing roads or between houses, avoiding eventual people contact to it must be a preference.

The given characteristics of the conductor are used in all the following calculations done to establish the size, length, and configuration of the distribution lines.
Table V. Characteristics of the Conductor for each Line

<table>
<thead>
<tr>
<th>Line</th>
<th>Main line</th>
<th>Line 7 (engine start-up)</th>
<th>1, 2, 3, 3.1, 4, 5, 5.1, 5.2, 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Name</td>
<td>Sparrow</td>
<td>Penguin</td>
<td>Turkey</td>
</tr>
<tr>
<td>Type</td>
<td>ACSR</td>
<td>ACSR</td>
<td>ACSR</td>
</tr>
<tr>
<td>Size (AWG - mm&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>2 – 33.62</td>
<td>4/0 – 107.2</td>
<td>6 – 13.30</td>
</tr>
<tr>
<td>Resistance AC @ 75 ºC (ohms/km)</td>
<td>1.08</td>
<td>0.39</td>
<td>2.64</td>
</tr>
<tr>
<td>Reactance @ 75ºC – 0.3m spacing. (ohms/km)</td>
<td>0.418</td>
<td>0.346</td>
<td>0.481</td>
</tr>
<tr>
<td>Weight (kg/100m)</td>
<td>13.54</td>
<td>43.30</td>
<td>5.35</td>
</tr>
<tr>
<td>Length per selling unit (m)</td>
<td>736.568</td>
<td>926.592</td>
<td>2729.484</td>
</tr>
<tr>
<td>Price per selling unit (USD)</td>
<td>452</td>
<td>362</td>
<td>481</td>
</tr>
</tbody>
</table>

b. Sizing of the conductor

It is important to be as accurate as possible with the following calculations to establish the size of the conductor for each line, as the cost of the conductor is one of the main expenses in the implementation of a mini-grid. Also the performance of the grid is dependent on the accuracy of the estimations and results obtained, an established sized smaller than the required could lead to problems in the electricity supply. The sizing is dependent on the load that has been estimated previously.

Once the design of the mini-grid and the loads are established, the determinant factors to maintain an acceptable voltage level are the type and size of the conductor and the power factor determined per line. So, in the next steps, the power factor and the voltage drop are described. The data, related to the conductor, needed to make the following calculation is given below, Table V (Southwire, 2001; Nexans, 2011).

- The power factor (PF)

The PF is dependent on the uses of the electricity. For an incandescent light bulb the power factor is 1, the maximum, while a fluorescent light can reach 0.6 (Inversin, 2000). To calculate the power factor of the main 4 customers: household, stores, schools and productive uses, the characteristics of the loads are taken in account. As it is not possible to assess the power factor of all the items connected, the main end-users have been analyzed to see which components are connected in each case, and in that way, estimate which can be the power factor. The estimations made are always bearing in mind the importance that a big difference between the real power factor and the estimated one could mean, regarding the performance, problems and possible failures.
For this case is important to state that the mill needs of an electrical motor to work. Thus, the characteristics of it are stated below; see Figure VII. These characteristics are used in the rest of calculations that are made further on.

<table>
<thead>
<tr>
<th>Part Detail</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision: B</td>
<td>Status: PRD/A</td>
</tr>
<tr>
<td>Type: AC</td>
<td>Prod. Type: 0044M</td>
</tr>
<tr>
<td>Enclosure: TEFC</td>
<td>Mech. Spec: D1H154</td>
</tr>
<tr>
<td>Frame: D180M</td>
<td>Mounting: B3</td>
</tr>
<tr>
<td>Base: RG</td>
<td>Rotation: R</td>
</tr>
<tr>
<td>Leads: #12</td>
<td>Literature:</td>
</tr>
<tr>
<td>proprietary: No</td>
<td>CD Diagram:</td>
</tr>
<tr>
<td>Created Date: 10-21-2009</td>
<td></td>
</tr>
</tbody>
</table>

**Figure VII. Characteristics of the Electrical Motor**

The Table VI shows the estimated PF of each of the elements included in the mini-grid. As said before, the data in Table VI is an estimation, and the relevance is depending on the importance of each element within the grid, that is the energy consumption that each has over the total consumption.
Regarding what mentioned before about power factor limits (between 0.6 and 1), and relating the estimations with the percentage of load per customer, the different assumptions for the power factor have been made, as accurate as possible and trying to generous, reaching a lower power factor to be in the safe-side for the design issues. So, in the Table VII it is a list of the final PF. The estimations are based on the information at researchers’ disposal; when the PF is unknown, is estimated as 0.6, the lowest, worst possible scenario. An average PF is calculated for each final user, as it is what is relevant for the calculations, the PF at the end of the line.

Table VII. Power Factor Estimation

<table>
<thead>
<tr>
<th>Customer</th>
<th>Power factor estimation</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households</td>
<td>75% =1; 25%=0.6;</td>
<td>0.9</td>
</tr>
<tr>
<td>Store</td>
<td>20%=1; 80%=0.6;</td>
<td>0.68</td>
</tr>
<tr>
<td>School</td>
<td>64%=1; 36%=0.6;</td>
<td>0.85</td>
</tr>
<tr>
<td>Productive Activities</td>
<td>58%=0.86; 1%=1; 41%=0.6;</td>
<td>0.75</td>
</tr>
<tr>
<td>Average global power factor</td>
<td></td>
<td>0.795</td>
</tr>
</tbody>
</table>

Once the PF is calculated, the next step is to find to the voltage drop per each line. The calculation of the PF for each line depends on the load it has to bear. And so, as example, the PF for the “main line” is; see Equation III.

Equation III. Power Factor

\[
PF (main\ line) = \frac{(PF\ Househol + PF\ Store + PF\ School)}{3} = 0.81
\]
- **Voltage Drop (VD)**

High voltage drops in the line will lead to a poor service, creating distrust and so, a future loss regarding potential new customers and demand of the service. The possible voltage drop has to be analyzed in order to minimize it. The voltage drop can be reduced by an increase of the conductor size.

After assessing the distribution of the line, the loads and its layout, it has been decided to treat each line independently assuming all the load at the end of the line, and in that way, have a more accurate view of what are the exact voltage drops per line. This deep analysis allows the researchers to treat differently each line if it is needed. The calculation of the voltage drop per each line is long and complicated, and so, an example is stated for the line 7. It is understandable that the same process has to be applied to the rest of the lines. The case of line 7 is special because of the electrical motor start-up.

To calculate the voltage drop per line there are 4 equations that must be applied; there are also a few concepts that must be introduced before for a better understanding of the equations; see Table VIII.

<table>
<thead>
<tr>
<th>Sign</th>
<th>Element</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>VD</td>
<td>Voltage Drop</td>
<td>Volt</td>
</tr>
<tr>
<td>E</td>
<td>Nominal Voltage</td>
<td>Volt</td>
</tr>
<tr>
<td>P</td>
<td>Power Input</td>
<td>kW</td>
</tr>
<tr>
<td>I</td>
<td>Intensity</td>
<td>Amperes</td>
</tr>
<tr>
<td>( \cos \phi )</td>
<td>Power Factor</td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>Line reactance</td>
<td>Ohms/km</td>
</tr>
<tr>
<td>r</td>
<td>Line resistance</td>
<td>Ohms/km</td>
</tr>
<tr>
<td>L</td>
<td>Longitude of the line</td>
<td>Meters</td>
</tr>
<tr>
<td>Pl</td>
<td>Power loss</td>
<td>kW</td>
</tr>
</tbody>
</table>

Once the elements that are going to be used have been defined. The next step is to give the values of each of those elements for the “main line” characteristics, see Table V. The application of the values in Table V in the following equations (see Equation IV, V, VI and VII) will give the results in Table IX.

The voltage drop (VD) per phase is shown in the Equation IV; in order to calculate the VD it is needed the intensity, which is calculated in the Equation V. Then, the Equation VI calculates the power loss. To conclude, the percentage of power loss compared to the total power supplied is calculated by the Equation VII.

**Equation IV. Voltage Drop**
After applying these equations, the voltage drop can be calculated for all the lines. The results are shown in the Table IX.

### Table IX. Voltage Drop per Line

<table>
<thead>
<tr>
<th>Line</th>
<th>Conductor Size (AWG)</th>
<th>Voltage Drop</th>
<th>Power Loss</th>
<th>% Power Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>2</td>
<td>11,92241177</td>
<td>117,4871717</td>
<td>1,174871717</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>0,047944065</td>
<td>0,067005479</td>
<td>0,008590446</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>1,524486062</td>
<td>3,772290809</td>
<td>0,18861454</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>1,559582342</td>
<td>2,993197279</td>
<td>0,199546485</td>
</tr>
<tr>
<td>3.1</td>
<td>6</td>
<td>0,203264808</td>
<td>0,201188843</td>
<td>0,025148605</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0,479440655</td>
<td>0,670054787</td>
<td>0,08590446</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>1,728604814</td>
<td>7,336121633</td>
<td>0,21964436</td>
</tr>
<tr>
<td>5.1</td>
<td>6</td>
<td>2,089840338</td>
<td>3,583056689</td>
<td>0,26739229</td>
</tr>
<tr>
<td>5.2</td>
<td>6</td>
<td>0,325223693</td>
<td>0,257521719</td>
<td>0,040237769</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1,170326932</td>
<td>1,174291939</td>
<td>0,209694989</td>
</tr>
</tbody>
</table>

Before concluding with this sizing, a key factor must be accounted, the start-up conditions of the motor connected to line 7 (Productive Uses). A huge voltage drop during the starting-up of the engine could lead to a bad performance, even to the impossibility to running the motor. The first step is to define the motor used and its characteristics; see Figure VII.

To calculate the input power (\(P_i\)) that the electrical motor needs for the start-up, the Equation VIII is used; \(\eta\) is the efficiency of the motor, is 0.914 (see Figure VI); \(\cos \phi\) is the estimated PF for the start-up, defined as 0.76, lower than the normal; \(P_o\) is the output power desired, in this case 7.5 kW.

\[
P_i = \frac{P_o}{\eta \times \cos \phi}
\]
Equation VIII. Input Power

The intensity of the current, needed to start-up the motor is estimated to be 6 times the normal intensity. The Equation IX shows the procedure to calculate the intensity. The nominal voltage (E) is 400 Volts.

\[ I_{\text{start-up}} = \left( \frac{P_i}{3 \times E} \right) \times 6 \]

Equation IX. Intensity for the Start-up

Once the intensity is known, the voltage drop suffered can be calculated.

\[ VD = I_{\text{start-up}} \times (r \times \cos \phi + x \times \sin \phi) \]

Equation X. Voltage Drop

The absolute power loss (Pl) and the percentage Pl is calculated following the Equation XI and the Equation XII.

\[ P_l = r \times I_{\text{start-up}}^2 \times L \]

Equation XI. Power Loss During the Start-up

\[ P_l(\%) = \left( \frac{P_l}{P_i \times 1000} \right) \times 100 \]

Equation XII. Power Loss Percentage During the Start-up

The characteristics that are used for these equations are in the Table V. The result of these calculations is shown in table X.

<table>
<thead>
<tr>
<th></th>
<th>Normal functioning (cos(\phi)=0.86)</th>
<th>Start-up (cos(\phi)=0.76)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_i) (w)</td>
<td>9541.49</td>
<td>10796.95</td>
</tr>
<tr>
<td>Intensity (A)</td>
<td>7.95</td>
<td>53.984</td>
</tr>
<tr>
<td>VD(%)</td>
<td>4.0698</td>
<td>28.1231</td>
</tr>
<tr>
<td>Power Loss (w)</td>
<td>2.4648</td>
<td>113.656</td>
</tr>
<tr>
<td>Power Loss (%)</td>
<td>0.2583</td>
<td>1.052</td>
</tr>
</tbody>
</table>

The line 7 uses the ACSR of 107.2 mm\(^2\). It allows a better performance for the motor to start-up and, obviously, it improves the outputs of the smaller sizes. Although, it has
unavoidable drawback that is imply in its size, more amount of material is needed, thus, more costly.

After the analysis of the conductors for all the lines, the following conclusions can be extracted:

- The voltage drops, thus, power losses are very small, almost all are under the 1%.
- Most of the lines use the same sizing so it simplifies the implementation and is likely to reduce cost as the demand is higher
- The Line 7 is treated separately because it has to bear the start-up of the engine. After a deeper assessment, the size previously selected has had to be removed due to performance problems.
- The fact that the size of the conductors is small will have a positive economical effect in two ways. First, the investment cost is lower, and secondly, the possible repair or replacement of wires is easier and cheaper than using bigger sizes.

The final characteristics of the conductors are shown in the Table XI.

**Table XI. Final Characteristics of the Conductors for all the Lines**

<table>
<thead>
<tr>
<th>Line</th>
<th>Conductor Size</th>
<th>Length (km)</th>
<th>Total length/conductor (km)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>2</td>
<td>0.37</td>
<td>1.48</td>
<td>12.58</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>0.01</td>
<td>5.4</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0.15</td>
<td>5.1</td>
<td>6.8</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>0.2</td>
<td>6.8</td>
<td>1.7</td>
</tr>
<tr>
<td>3.1</td>
<td>6</td>
<td>0.05</td>
<td>1.7</td>
<td>3.4</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0.1</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>0.1</td>
<td>3.4</td>
<td>10.2</td>
</tr>
<tr>
<td>5.1</td>
<td>6</td>
<td>0.3</td>
<td>10.2</td>
<td>3.4</td>
</tr>
<tr>
<td>5.2</td>
<td>6</td>
<td>0.1</td>
<td>3.4</td>
<td>11.56</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0.34</td>
<td>11.56</td>
<td>10.72</td>
</tr>
<tr>
<td>7</td>
<td>4/0</td>
<td>0.1</td>
<td>0.4</td>
<td>69.2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.82</td>
<td>7.28</td>
<td></td>
</tr>
</tbody>
</table>

As the configuration of the system is three-phase four-wire, the total length of conductor that is needed is four times the length per line, because each line has three phases and the neutral. As it can be seen in the Table XI, the largest amount of cable is needed for size 6 AWG, which is the used in the majority of lines.

**Cost of Conductor**

The total cost of the conductor per each line is dependent on three main factors. The cost of the material, the transport of it and the installation costs.

**Cost of Material**

The calculation of the total cost of the material is according to the data given by the
supplier of the ACSR (Southwire, 2011). The data is collected in the Table XII.

<table>
<thead>
<tr>
<th>Type</th>
<th>Total length (km)</th>
<th>Total km/unit</th>
<th>Number of units needed</th>
<th>Weight per unit (kg)</th>
<th>Cost (USD/kg)</th>
<th>Total Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.48</td>
<td>2.955</td>
<td>1</td>
<td>400.975</td>
<td>9.964</td>
<td>3995.68</td>
</tr>
<tr>
<td>6</td>
<td>5.4</td>
<td>4.698</td>
<td>2</td>
<td>400.975</td>
<td>10.604</td>
<td>8504.08</td>
</tr>
<tr>
<td>4/0</td>
<td>0.4</td>
<td>0.926</td>
<td>1</td>
<td>400.975</td>
<td>7.980</td>
<td>3200.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Total cost of conductor material (USD)</strong></td>
</tr>
</tbody>
</table>

As can be seen in the Table XII, the total cost of the ACSR material is 15,699.84 U.S. Dollars.

**Transport**

The transportation costs of the material to the area where the mini-grid is implemented are hard to state and are also dependent on the supplier and on the customer. In order to evaluate the cost in a reliable way, the examples given in the mini-grid design manual (Inversin, 2000) have been taken in account; the transport arises as one of the main costs of the whole project. The case of the El Limón, in the Dominican Republic can be taken as an example, the international transport of the materials cost up to 17% of the total budget. In the case under study, the 20% of the cost of the material will be taken as the transport costs.

**Labor and construction costs.**

The labor and construction costs are also very difficult to assess without the appropriate data and especially in developing countries where there is a greater lack of regulations regarding wages and job conditions. As it has been made for the transportation cost case, an example from the bibliography has been used in order to evaluate the cost of labor and salaries for the physical implementation of the project. In the table of the mini-grid design manual, table 28 (Inversin, 2000 p.237), the labor cost per conductor is stated. In this case, the data used is equivalent to the one given for a 4-wire configuration, the same that is used in the project, and size and conductor type #6-ACSR.

<table>
<thead>
<tr>
<th>Total length (km)</th>
<th>Cost (USD/m)</th>
<th>Total Labour Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.28</td>
<td>0.44</td>
<td><strong>3203.2</strong></td>
</tr>
</tbody>
</table>

The Table XIII shows the data taken from the table 28 (Inversin, 2000 p.237) previously mentioned. In that way is possible to obtain a value for the construction cost of the mini-grid lines.
**Total Cost for the conductor**

Merging the results of the cost for the material, transport and labor, it easy to obtain the final cost of the conductor for the mini-grid implementation. The table XIV shows the total budget just for the conductor.

<table>
<thead>
<tr>
<th>Category</th>
<th>USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>15699.84</td>
</tr>
<tr>
<td>Transport</td>
<td>4725.76 (20% of conductor total cost)</td>
</tr>
<tr>
<td>Labour</td>
<td>3203.2</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>23628.8 US Dollars</strong></td>
</tr>
</tbody>
</table>

**VI. Poles**

The importance of poles is really high in grid extensions that are not spread underground. The fact that the roads and the paths along the village are used to wire the area gives even more importance to the shape and structure of the poles, due to the traffic of vehicles and people passing underneath the electrified cables. The hazard to people’s health could be highly increased if the poles are not suitable for the area where are placed.

The problem for poles’ design is that, in this study and due to economical facts, the poles’ raw material is taken from the surrounding area of the village. Using local materials would greatly reduce the potential costs of the whole mini-grid project, as it can be seen in other examples (Inversin, 2000) poles’ budget is one of the main costs of the entire mini-grid. Besides, it is decided not to use a very technical approach here because about this part there is absolutely no data from the locals or the field trips. The main problem related to the use of local materials is the possible environmental harm. In this case and due to the dimensions of the grid, it has been supposed that the amount of poles needed would not be a problem for the forestry sustainability of the area.

The further calculations regarding poles, its potential tensions, fixing them to the ground, etc. are not accounted in this study. The ignorance about wind’s load or other key factors to bear in mind when studying the performance of poles forces the researchers to drop the more exact calculations at this point. The data given regarding poles layout and characteristics are;

**Material**: Local wood source used.

**Minimum high** (for bare phase conductor in areas with vehicular traffic in the U.S.A): 5m (Inversin, 2000).

Number of poles: 43

Span: different span lengths according to the layout of the system.

The relation between the lines, the poles and its span length has been calculated in the Table XV and Table XVI. The list of the poles is done according to the mapping of the
area. In the following snapshot, Figure VIII, the main poles and the different lines are highlighted in order to have a better understanding of how the system would look at the end.

Table XV. Pole Distribution of the Main Line

<table>
<thead>
<tr>
<th>Line</th>
<th>Pole</th>
<th>Pole-to-Pole</th>
<th>Span (m)</th>
<th>total line (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of the Main Line</td>
<td>1</td>
<td>1-2</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2-3</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3-4</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4-5</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5-6</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6-7</td>
<td>10</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>7-8</td>
<td>40</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8-9</td>
<td>40</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>9-10</td>
<td>40</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10-11</td>
<td>40</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>11-12</td>
<td>40</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>12-13</td>
<td>30</td>
<td>370</td>
</tr>
<tr>
<td>End of the Main Line</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>370</td>
</tr>
<tr>
<td>End of the Line 1</td>
<td>10</td>
<td>10-14</td>
<td>20</td>
<td>390</td>
</tr>
<tr>
<td>End of the Line 1</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>390</td>
</tr>
</tbody>
</table>
# Table XVI. Pole Distribution of the Mini-Grid Lines

<table>
<thead>
<tr>
<th>Line</th>
<th>Pole</th>
<th>Pole-to-Pole</th>
<th>Span (m)</th>
<th>total line (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Star of the Line 2</td>
<td>13</td>
<td>13-15</td>
<td>40</td>
<td>430</td>
</tr>
<tr>
<td>End of the Line 2</td>
<td>15</td>
<td>15-16</td>
<td>40</td>
<td>470</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>16-17</td>
<td>20</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>17-18</td>
<td>50</td>
<td>540</td>
</tr>
<tr>
<td>Cluster 1</td>
<td>18</td>
<td>18</td>
<td>0</td>
<td>540</td>
</tr>
<tr>
<td>Start of the Line 3</td>
<td>19</td>
<td>19-20</td>
<td>40</td>
<td>580</td>
</tr>
<tr>
<td>End of the Line 3</td>
<td>20</td>
<td>20-21</td>
<td>40</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>21-22</td>
<td>40</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>22-23</td>
<td>40</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>23-24</td>
<td>20</td>
<td>720</td>
</tr>
<tr>
<td>School 1</td>
<td>24</td>
<td>24</td>
<td>20</td>
<td>740</td>
</tr>
<tr>
<td>Line 3.1</td>
<td>25</td>
<td>24-25</td>
<td>50</td>
<td>790</td>
</tr>
<tr>
<td>Start of the Line 4</td>
<td>13</td>
<td>13-26</td>
<td>50</td>
<td>840</td>
</tr>
<tr>
<td>End Line 4</td>
<td>26</td>
<td>26-27</td>
<td>50</td>
<td>890</td>
</tr>
<tr>
<td>Trade Centre</td>
<td>27</td>
<td>27</td>
<td>0</td>
<td>890</td>
</tr>
<tr>
<td>Start of the Line 5</td>
<td>27</td>
<td>27-28</td>
<td>50</td>
<td>940</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>28</td>
<td>28</td>
<td>0</td>
<td>940</td>
</tr>
<tr>
<td>Line 5.1</td>
<td>27</td>
<td>27-29</td>
<td>40</td>
<td>980</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>29-30</td>
<td>40</td>
<td>1020</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>30-31</td>
<td>40</td>
<td>1060</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>31-32</td>
<td>40</td>
<td>1100</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>32-33</td>
<td>40</td>
<td>1140</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>33-34</td>
<td>40</td>
<td>1180</td>
</tr>
<tr>
<td>School 2</td>
<td>34</td>
<td>34-35</td>
<td>10</td>
<td>1190</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>35-36</td>
<td>50</td>
<td>1240</td>
</tr>
<tr>
<td>Line 5.2</td>
<td>36</td>
<td>36-37</td>
<td>50</td>
<td>1290</td>
</tr>
<tr>
<td>End Line 5</td>
<td>37</td>
<td>37</td>
<td>0</td>
<td>1290</td>
</tr>
<tr>
<td>Start of the Line 6</td>
<td>7</td>
<td>7-38</td>
<td>40</td>
<td>1330</td>
</tr>
<tr>
<td>End of the Line 6</td>
<td>38</td>
<td>38-39</td>
<td>40</td>
<td>1370</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>39-40</td>
<td>40</td>
<td>1410</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>40-41</td>
<td>40</td>
<td>1450</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>41-42</td>
<td>40</td>
<td>1490</td>
</tr>
<tr>
<td>Cluster 6</td>
<td>42</td>
<td>42</td>
<td>0</td>
<td>1490</td>
</tr>
<tr>
<td>Start of the Line 7</td>
<td>2</td>
<td>2-43</td>
<td>30</td>
<td>1520</td>
</tr>
<tr>
<td>End of the Line 7</td>
<td>43</td>
<td>43</td>
<td>0</td>
<td>1520</td>
</tr>
</tbody>
</table>
Figure VIII. Pole Distribution in Sekanyonyi
VII. Mini-Grid Design Conclusion

The design of a mini-grid comprises all the stages from the output of the power generator system, the source of electricity, to the end-user device. All the steps that must be performed in order to design the whole mini-grid system could be a report themselves, this fact added to the lack of reliable information and that the aim of the project is not to develop a mini-grid, pushed the researchers to just present an overview of a mini-grid example. And so, the data presented has to be taken as a general assessment, not as the exact design of a mini-grid. The calculations have been made as long as the researchers understood that the information given was relevant and actual, when a minimum point of reliability couldn’t be reached, the authors of the work decided to not perform the next stages of the design.

A more global view is needed to understand the general functioning of the mini-grid, and it involves all the stages as impact assessment, business model, etc. done before. The main purpose of the mini-grid design's overview has been to give a more real approach to how the mini-grid would look, and to have a basic understanding of its different parts, the economical costs and the technical issues regarding electrical engineering. The Figure IX shows the conceptual diagram of the mini-grid and its lines.

Appendix IX Sizing the Heat Pipe Exchanger

The calculation steps followed are taken from the brochure available in the website of the device supplier (Appendix V). The data relevant to the heat load in the container
and the temperatures is according to data provided by Pamoja Cleantech AB. The heat is estimated after assessing heat loss temperatures along the gasification process. It can appear that some data is not justified or some devices related to the heat recovery are not mentioned, as the gasifier, it is due to confidentiality issues about the GP project.

The Figure X shows a draft of the container with its dimensions, the dimensions are given in meters. It can be seen that is a common shipping container.

![Figure X. Container Draft with Measures](image)

The first step then is to calculate the heat load inside the container. This value is function of the temperature in and out the container and the area of it exposed.

The temperature are define as follows

\[ T_{\text{in}} = 70 \, ^\circ\text{C} \quad (158 \, ^\circ\text{F}) \]
\[ T_{\text{out}} = 28 \, ^\circ\text{C} \quad (82.4 \, ^\circ\text{F}) \] according to the data (aboutuganda.com, 200-)

The areas exposed

\[ A_1 = 8.6 \times 8 = 68.6 \, \text{m}^2 \]
\[ A_2 = 8.6 \times 20 = 172 \, \text{m}^2 \]
\[ A_3 = 8 \times 20 = 160 \, \text{m}^2 \]

The total area of the container is calculated in Equation XIII;

\[ \text{Area} = 2 \times A_1 + 2 \times A_2 + A_3 = 137.6 + 344 + 160 = 641.6 \, \text{ft}^2 \]

Equation XIII. Area of the Container

Then, the formula to account the heat load inside the container is shown in Equation XIV.

\[ p[W] = \frac{9 \times \text{Area} \times (\frac{1}{36}) \times (T_1 - T_2)[^\circ\text{F}]}{36} = \frac{9 \times 641.6 \times (158 - 82.4)}{36} = 12.126 \, \text{kW} \]
The used element in Equation XIV are described in the Table XVII.

<table>
<thead>
<tr>
<th>P</th>
<th>Heat Load in watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Total Exposed surface of the container</td>
</tr>
<tr>
<td>T₁</td>
<td>Temperature inside the container</td>
</tr>
<tr>
<td>T₂</td>
<td>Ambient Temperature</td>
</tr>
</tbody>
</table>

Table XVII. Elements Included in the Calculations of the Equation XIV

The heat load inside the container is up to 12.12 kW for the temperatures evaluated. And so, in order to see which of their models fits better to the needs of this application, the following formula is applied, see Equation XV:

\[ C = \frac{36 \times P[W]}{\Delta T[F]} - (9 \times Area[f t^2]) \]

Equation XV. Calculation of the Container Cooling Rating

The elements used in the Equation XV are described in the Table XVIII.

<table>
<thead>
<tr>
<th>C</th>
<th>Container Cooling Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Total Exposed surface of the container</td>
</tr>
<tr>
<td>ΔT</td>
<td>Allowable rise of temperature above ambient inside the container after the service is installed</td>
</tr>
<tr>
<td>P</td>
<td>Heat Load in watts</td>
</tr>
</tbody>
</table>

Table XVIII. Elements Used in Equation XV

The device chosen is related to the cooling rating, the supplier provides a table with the rating of each of the devices that can be purchased. The value for C obtained in the formula must be smaller than the value of the chosen device in order to reach the desired conditions. The different considered models and the value of C for each of them are shown in the Table XIX.

Table XIX. Relation of Absorption Chiller Model and Cooling Rating

<table>
<thead>
<tr>
<th>Installed Unit</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1200</td>
<td>1500</td>
</tr>
<tr>
<td>CC1400</td>
<td>1500</td>
</tr>
<tr>
<td>CC2000</td>
<td>2200</td>
</tr>
</tbody>
</table>

It is easy to see that the value of C is directly dependent on the temperature rise that is allowed inside the container. As in the case under study the area of the container is very
big, and the economic aspect is a big constraint, the temperature rise permitted will be up to 43 °F (23.8 °C). Thus, the result when applying this value to Equation XV is:

\[
C = \frac{36 \times P}{\Delta T} - (9 \times Area) = \frac{9 \times 12126.6}{43} - (9 \times 641.6) = 4377.6
\]

Equation XV. Calculation of the Container Cooling Rating

As the value is higher than the ones found in the table for air-to-air heat exchanger, two devices will be applied. Thus, following Equation XVI shows the result.

\[
C + C = \frac{36 \times P}{\Delta T} - (9 \times Area) \rightarrow 2 \times C = 4377.6 \rightarrow C = 2188.8
\]

Equation XVI. Calculation of the Container Cooling Rating if 2 Devices Applied

So, the model CC2000 is the appropriate for the system (appendix V).
- Cooling capacity = 2,19 kW
- Annual electricity consumption = 44,16 kWh/year. Assuming 120 days of activity and 8 hours of work a day.

The main idea of this application is to recover the waste heat inside the GP container and stream it inside a room where the coffee seeds will be stored, in that way, speed up the drying timing, reduce the process and allow the prevision of the next steps in the coffee procedure. The figure below, see Figure X, is an overview of how the system would work, a conceptual approach to what is intended to apply.

The conduct to stream the heat source is dependent on the distance between the heat source (GP) and the drying chamber. The possibilities to cover this tubing system are varied, since the application of thermally insulated pipes to the use of PVC, or other plastic tubes, previously covered with a special material that reduces the heat loss significantly. The economical cost of the piping is not going to be relevant when compared to the cost of the 2 devices needed for the application. So, it is decided not to include into the final budget.
Figure X. Conceptual Diagram of the Functioning of the Heat Pipe Exchanger