Sustainable Development: The Real Case Study of the Koinonia Community

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Abstract

The present thesis focuses on the topic of energy access and ecovillages, as model to achieve a sustainable community living, by investigating the topic of sustainable development through a real case in study. The theory has been put in practice to reach the sustainability of the Koinonia Community, located in Lusaka, Zambia.

The first major proposal regards the optimization and replacement of the cooking method, charcoal based, of the Mthunzi Centre, the orphanage located in the Community. Three technologies are proposed: a microgasifier, an LPG stove and a biogas and LPG mix. The microgasifier resulted the more sustainable technology reaching a positive NPV, equal to 23,357 € and a CO2 equivalent reduction of 94% respect to charcoal.

The other assessment regards a feasibility study focused on the design of a stand-alone solar pumping system. The double objective is to test innovative flexible solar modules and to supply water to the agriculture school in the Community. Three system settings are proposed, two using batteries and one a water storage. The later demonstrated to be the most affordable and scalable for rural areas, with a LCOE equal to 0.103 €/kWh for the self-financing case and 0.034 €/kWh for the donation case.

Finally, to reach the sustainability of the Community, the creation of a local business is developed. The project aims to produce charcoal from solid bamboo. The pilot project demonstrated the profitability of the venture with a profit of 34 € per day for the analysed case.

Keywords: Sustainable development, energy access, ecovillages, developing countries, solar pumping systems.

1. Introduction

The specific motivation behind this thesis is to investigate the potentiality and the modality for the creation of sustainable communities through the access to energy. Nowadays, energy is considered one of the main engines of sustainable development, being the access to energy the 7th Sustainable Development Goal as demonstrated by United Nations (1).

The aim of this thesis is to present a new paradigm that uses as approach the ecovillage model. Ecovillages are virtuous examples of low impact communities that can create personal and community empowerment and emancipation. To achieve their sustainability, they cannot deny the contribution of renewable energies.

This thesis will try to link the energy access topic with the will to create an ecovillage in the Community of Koinonia, Lusaka, Zambia. The mentioned Community will be used as example to show a potential alternative for rural communities in developing countries.

2. Case Study and Objectives

"Koinonia Community Society" is a charity in the Republic of Zambia and it is active since 1982. The Community, founded by Father Kizito, has several people ranging from 200 to 250 individuals, variable depending on the time. Koinonia is in the area of Kasupe, about 15 km west of Lusaka. The total area available is approximately 40.5 hectares. The land is owned by the whole community and is managed by administrators, who oversee ensuring its correct use.

In the centre of the Koinonia's area, there is the orphanage called, Mthunzi centre. It was founded in 2000, it is one of the largest facilities in the community. It is funded with donations from the Italian NGO, AMANI. The facility can accommodate as residents up to 60 former street children.

The future goal of the AMANI NGO is to improve the supply chain of agricultural products as well as optimize the community's water and energy system. The community is connected to the electrical grid. Most of its inhabitants and residents in the Mthunzi Centre are currently cooking with charcoal.

In this context, the main objectives of this thesis are divided into three main topics: electricity access, clean cooking access and business creation.

Regarding clean cooking access, the following goals can be identified:

1. Replacement of traditional cooking method based on charcoal.
2. Reduction of energy cost.

Regarding electricity access:

1. Implementing a feasibility study to size a solar pumping system.
2. Investigate the potentiality of this technology for rural areas.

Business creation:

1. Generation of income.
2. Generation of Jobs in local communities.

3. Clean Cooking Access

Currently, in the Mthunzi Centre, charcoal is used to cook for the 40 hosted children and the staff of the centre. The local NGO has explicitly expressed the desire to substitute the current polluted and expensive technology. The present work will look in details three main opportunities to substitute the charcoal-based technology: using an improved biomass cookstove, in the specific the microgasifier Elsa, using an LPG stove and using a mix of biogas an LPG. The three alternatives have been compared on an economic and ecologic perspective with the charcoal stove.

First of all, the current thermal energy needs of the Mthunzi centre have been assessed. The charcoal is used in a traditional stove. The consumption of charcoal has been initially quantified by accounting for the Kgs consumed per day, thus, the final energy consumption has been accounted. Consequently, the specific characteristics of the stove have been identified, in order to obtain the useful energy necessary to cook.

To quantify the thermal energy necessary to cook, the efficiency of the stove has been tested. The overall thermal efficiency of the stove has been found using the water boiling test. The water boiling test is a simulation of the cooking process to measure the efficiency of a burner and a given fuel, in transferring heat to a pot with a precise quantity of water (2).

Three tests were performed, and the average thermal efficiency has been obtained. By having that value, it has been possible to obtain the useful thermal efficiency to provide the required thermal energy needs in the Mthunzi centre.

The obtained values are summarised in Table 1. Those value are crucial to perform optimization measures and look for a more sustainable cooking alternative.

Table 1: Charcoal Consumptions

	Units	**Charcoal**
Net calorific value	kWh/kg	8.3
daily consumption	Kg	40.5
final energy consumption	kWh/day	335.3
Cost per 27 Kg bag	Euro/bag	5.4
Cost per Kg	Euro/kg	0.2
Energy Cost	Euro/kWh	0.024
Annual cost	Euro/year	2948.1

3.1. Cooking Alternatives

The first alternatives that it is presented is the use of the micro-gasifier Elsa, presented in Figure 1. This specific technology was built by the author of the thesis during a workshop with the company Blucomb, promoted by the University of Udine. The design was made by the former company during the project Biocharplus, developed by the University of Udine (3).

The Elsa burner is a type of reactor in which separate phase combustion takes place, it means that the 3 phases of combustion take place separately in time and space: drying, pyro gasification and combustion.

Figure 1: Elsa Microgasifier (3)

This micro-gasifier can be identified as a TLUD burner and it is a specific type of improved biomass cookstove. By the reactions that take place in the burner, 2 main products are produced: the syngas, that is burnt at the top of the microgasifier, and the biochar, demonstrated by many researches an excellent soil improver.

The Elsa microgasifier has been tested using the same methodology of the charcoal stove: the water boiling test. First, a market analysis has been performed to find a suitable biomass able to fuel the burner. It has been chosen to use pellet, being the best option from a technical and economic point of view. Consequently, three tests were performed and an average efficiency of 34% was obtained. Finally, a training session with the cook has been arranged, to let she familiarise with the technology.

In the thesis, the second alternative presented is represented by the LPG stove. It is recognised as a technology that can provide important benefits in terms of emission reduction, health, forest protection and economic development. The LPG has a Net Calorific Value of 12.20 kWh/kg and. LPG stoves have an overall thermal efficiency of around 60 % (4). This value considers both the combustion efficiency and the efficiency of the heat transfer.

The last alternative, that was investigated, is the local biogas production from anaerobic digestion. The anaerobic digestion it is a biochemical process in which under free oxygen conditions there is the degradation of the organic matter by micro-organisms, producing a gaseous mixture called biogas and a solid-liquid phase called digestate or bio-slurry. The anaerobic reaction occurs in a digestor. Three main digestors are used in rural contexts of developing countries: fixed-dome digestor, floating-dome digestor and tubular one. The fixed dome has been chosen for the present case study, showing the best performances from a technical and economic perspective, it is shown in Figure 2.

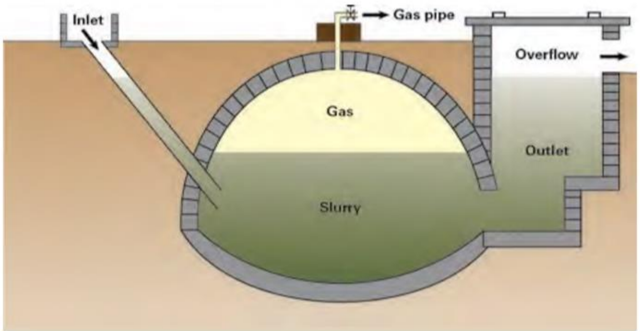

Figure 2: Fixed dome digester (5)

First of all, an analysis of the resources has been performed. Two main biomasses can be collected in the community to produce biogas, such as pigs' manure and humans' excreta. Then, the volume of the digestor was sized according with the potential biogas production by the available biomasses. An 8 m3 fixed dome digestor has been chosen. It has been found that the current production of biomasses cannot cover the energy needs of the Mthunzi Centre. Consequently, it has been considered to use a mix of LPG and biogas to cook in the Centre. Specifically, 54% of the total final energy needs to be covered by LPG and the remaining is covered by biogas.

In the Table 2, the three technologies are compared with the charcoal stove. Specifically, it was noticed an energy savings from all the three alternatives.

Table 2: Cooking options comparison

	Units	Charcoal	Pellet	LPG	Biogas and LPG
Net Calorific Value	kWh/kg	8.30	4.80	12.20	5.42 and 12.2
Useful Energy Consumption	kWh/day	48.96	48.96	48.96	48.96
Overall thermal efficiency	%	14.6	34	60	58
Final Energy Consumption	kWh/day	335.34	144	81.60	84.08
Final Energy Saving	%	-	57	76	75

It can be noticed that the LPG stove represent the best technology in terms of energy saving. This is because it has the higher Net Calorific Value and the higher efficiency compared to the others technology.

3.2. Economic and environmental assessment

An economic assessment has been performed to identify the most affordable technology and fuel. Two main parameters are used to compare the economic saving of each alternative with the charcoal stove. The Net Present Value has been found for each technology in comparison to the energy cost of charcoal, for a project lifetime of 20 years. The results are displayed in Table 3. It can be noticed that the microgasifier resulted the most competitive alternative.

Table 3: NPVs comparison

	NPV
Microgasifier	23,357
LPG	-7,112
Biogas and LPG	17,921

Consequently, the levelized cost of energy (LCOE) has been computed for each technology, including the charcoal stove. It has been found discounting the useful thermal energy supplied by each technology. The results are displayed in Table 4.

Table 4: LCOE for the different options

	Charcoal	**Microgasifier**	**LPG**	**LPG and Bio-gas**
LCOE (Euro/MWh)	165	80	187	110

In conclusion, an environmental assessment has been performed, to quantify the CO2 equivalent emissions from each cooking method. As it is shown in Table 5, the microgasifier resulted to be the less polluted technology in terms of CO2 equivalent emission.

Table 5: Emission Saving for the specific cooking options

	Charcoal	**Microgasifier**	**LPG**	**Biogas and LPG**
Annual Useful Energy (MJ)	17.9	17.9	17.9	7.76 and 9.97
Emission Factor (gCO2_e/MJ)	29.7	1.7	196.2	5.1 and 196.2
Annual Emission (gCO2_e)	530.75	30.4	3506.17	1995.7

4. Electricity access

The electricity access topic is developed in chapter 4. This chapter aims to study the feasibility of the implementation of a solar pumping system. This project is implemented with the support of two Italian companies: Caprari and KeyFuture. Their objective is to quantify the performance of a solar pump powered by flexible solar modules. This technology can result suitable to provide energy in remote areas and emergencies. In the specific, the aim is to use the system to supply water in the agriculture school of the Koinonia community. First of all, the water consumption was analysed. It is forecast to supply the water to the residents of the school and a small plantation of solid bamboo by drip irrigation. Consequently, the hydraulic system has been selected considering the water demand. The hydraulic system is formed by the following part:

- Well
- A 0.37 kWh submergible water pump
- Water storage. A tank of 5000 litres
- Pipe system
- Irrigation system

Then, three different electrical system has been compared for performances and costs.

Case 1: the system is equipped with the flexible solar modules, a controller/inverter and batteries. In this simulation it is assumed that the pump is turned on early in the morning at 6 a.m.

Case 2: the system is equipped with the flexible solar modules and a controller/inverter. The water tank is used in this case as the only energy storage system. The water is pumped in the tank when there is enough solar energy. In this simulation has been simulated to let operate the pump during the best solar time, around solar noon. The load profile has been configurated as normal distribution around solar noon. Consequently, the pump is turned on at 9:30 a.m. during the hot season and at 10:30 during the winter and rainy seasons.

Case 3: this case has the same system setting of the case 1 (Flexible solar module, inverter/controller and batteries). It is simulated using the same load profile of the Case 2.

In the specific, the following components are used:

- Flexible solar modules with a Maximum Rated Power of 92 W;
- Keyfuture controller and inverter;
- Hoppecke 10 OPZS lead-acid batteries are considered. They have a nominal capacity of 1500Ah, a rated voltage of 2 V;

Knowing both components and load profiles, the system has been designed and sized for each of the three cases using the energy software Homer. The results of the simulations are displayed in Table 6.

Table 6: Systems Components

Components	**Units**	**Case 1**	**Case 2**	**Case 3**
Pv modules	kW	0.46	0.736	0.368
	Numbers	5	8	4
Batteries	Numbers	1	-	1
Inverter/controller	KW	2	2	2

Consequently, from the estimation performed by the software, the relevant parameters can be forecast. The results are shown in Table 7.

Table 7: Potential energy production

Relevant DATA	**Units**	**Case 1**	**Case 2**	**Case 3**
Annual energy production	kWh/year	766	1,226	613
Annual energy consumption	kWh/year	449	430	443
Unmet Load	kWh/year	23.2	42.2	29.5
	%	4.9	9.01	6.23

Excess Electricity	kWh/year	223	759	108
Batteries autonomy	hrs	31	-	31

As it was expected, the case 2 is less reliable than the other 2 cases, since the Unmet load are almost double than the case 1. The use of a higher number of batteries can provide a lower value of the unmet load. On the other hand, the case 1 can produce two times more energy than the case 3, but, the respective quantity of energy is wasted.

The economic feasibility of the project will analyse all the three potential systems, for all the three presented cases. As well as for the economic analysis implemented in chapter 3, the LCOE and the NPV will be taken into consideration to compare the three cases. In particular, the LCOE will be used to compare the cost of energy for all the three systems with the electricity cost in Zambia, provided by the national grid.

Moreover, two ways of financing the project have been investigated:

1. Through a donation of the system. The initial investment cost is covered by a donor. The beneficiary will need to cover the maintenance cost and the replacement cost.
2. Through a self-financing of the System. The beneficiary needs to cover all the cost related to the implementation and running of the project.

In Table 8 the three cases are compared in terms of NPC for both the financing methods.

Table 8: NPCs for the three cases

	Units	**NPC Case 1**	**NPC Case 2**	**NPC Case 3**
Sel-financing	Euro	3380.0	1835.3	3313.7
Donation	Euro	1561.2	604.6	1552.8

The most affordable solar system is the one arranged for case 2. This is mainly because there is no energy storage.

Consequently, it has been computed the LCOE for the three cases and the two financing options.

Table 9: Levelized cost of energy of the three cases

	Units	**Case 1**	**Case 2**	**Case 3**
Self-financing	Euro/KWh	0.31	0.103	0.385
Donation	Euro/kWh	0.14	0.034	0.18

Comparing the national energy tariffs with the computed LCOEs, it has been noticed that there is no type of system and donation stream able to compete with the subsidised energy tariffs of 0.012 Euro/kWh. Only the LCOE referred to the system of case 2, financed throughout donation, can compete with the not subsidised national tariff, equal to 0.055 Euro/kWh (6).

It can be consequently concluded, that to compete with the electricity tariffs in Zambia, provide monetary aids is necessary.

5.Business Creation

It is crucial to generate income in rural areas to let inhabitants achieve a sustainable development. In the Chapter 5, it is shown an example of a sustainable business that can generate an economic development, reducing the impact of human being on forest depletion.

On a local scale, the project wants to create a small-scale business based on a sustainable view. The project is developed with the partnership of the Koinonia community and it would create an income able to finance and self-sustain the community's projects. Moreover, it has as objectives the idea of creating employment both to the orphanage that has finished their school careers and both to the inhabitants of the community.
To achieve those objectives, it will be investigated the opportunity to produce charcoal out of a more sustainable source: the solid bamboo.
First, some tests were performed. The charcoal has been produced using a more efficient method compared to the traditional one. A gasifier, produced by the author of the thesis with the contribution of local people, has been build. It has been demonstrated to achieve a carbonization yield on average equal to 40%, meaning that from 100 kg of solid bamboo were obtained 40 kg of charcoal.

Figure 3: Sample of solid bamboo and the obtained charcoal

Consequently, a cost and benefits analysis has been performed. That have proved the profitability of the business with a profit of 34 € per 20 bags of 50 kg each per day. Future works will be focused on scaling up the business to understand the validity on a country level.

6.Conclusion and future works

The present thesis would like to be an example on how to sustain the development of eco-friendly communities. It is crucial to respect the environment to achieve a community living and create social and spiritual harmony between people.
The Koinonia Community is a context that reflects the challenges and the situation of similar rural villages in Zambia and developing countries.
First of all, the topic of the clean cooking access was addressed. In the Mthunzi Centre, traditional cooking methods, based on the combustion of charcoal, are still used. Three potential alternatives were presented: using a microgasifer, an LPG stove and a mix of biogas and LPG. All the three methods presented a relevant energy saving in comparison with the traditional technology. Nevertheless, the microgasifier was the most economically sustainable presenting a NPV positive and higher than the others cooking methods. In the specific it has given a NPV equal to 23,357 € respect to charcoal. The former was even giving the best results in terms of reduction of CO_2 equivalent emissions, reaching a reduction of 94% on the emissions respect to charcoal.

In this framework, future works have the aim to spread the microgasifier technology in the Koinonia Community and in nearby areas. Well organised and detailed trainings are crucial for the successful introduction of the new technology.
The other main topic, that this work addressed, was the development of a feasibility study for the implementation of a stand-alone solar pumping system for the agriculture school, located in the Community. The system is provided with flexible PV modules. Specifically, three potential system settings were simulated. Two system settings used an electrochemical storage and one a water storage system, pumping water when solar energy was adsorbed. The use of a water storage resulted to be more convenient in terms of energy production and economic saving, considering both the initial investment and operational costs. On the other hand, the use of an electrochemical energy storage resulted to have higher NPCs. The LCOE for the setting used in the case 2, with water storage, has been the lowest among the other cases. In the specific, for this system the LCOEs resulted equal to 0.103 €/kWh for the self-financing case and 0.034 €/kWh for the donation case.
To scale up this project and spread this innovative technology in rural areas affected by lack of irrigation systems, it is necessary to understand the willingness to pay of small-holder farmers. Further studies need to be developed to understand if this system can be economically sustainable, rising the income of farmers through a more efficient water supply.
In the last chapter, it was presented the current work of the author of the thesis. The generation of productive activities, engines of the economic growth, is fundamental for the achievement of sustainable development. Following this mind-set, the importance of create a local business in the Community has been a good way to increase the income of inhabitants. The project consists mainly in the creation of a production of charcoal made from a sustainable biomass: the solid bamboo. From the performed tests and market analysis in a specific area of Lusaka, it has been proved the profitability of the business. From the pilot project, the profitability of the system has been demonstrated, with a production per day of 20 bags of 50 kg each the daily profit is equal to 34 €. That profit corresponds to the average monthly income in Zambia.
Future studies will aim to improve the efficiency of the production process. Moreover, the scalability of the project will be researched. Finally, the social and environmental impact of the project will be better investigated.
The period spent in the Koinonia Community has been useful for the understanding of needs and challenges that most of the Zambian population addresses every day. The differences between developing and developed countries are dramatically relevant, mostly concerning the supply, habits and consumptions of energy. It cannot be denied the importance of energy to reduce the global poverty. It cannot either be denied that a strong cooperation among people and countries has a relevant importance towards the reduction of the social and economic gap between human beings. The cooperation starts first of all from the knowledge of the other. If there is a technological gap between nations doesn’t mean, there is a human superiority or inferiority. All the human beings are equals.

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